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COMBUSTION MODIFICATION CONTROLS FOR STATIONARY GAS TURBINES - VOLUME II: UTILITY UNIT FIELD TEST

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16. ABSTRACT The report gives methods and results of an environmental assessment test program at Houston Lighting and Power's T.H. Wharton Generating Station, Unit 52. The aim of the program was to measure emissions changes resulting from applying NOx controls. Emissions of trace elements, organic materials, sulfur species, SO2, NOx, CO, and particulate matter were measured. These emissions, under normal and controlled (for NOx) operating conditions, were compared. Source operating data were also analyzed so that changes in operating parameters and efficiency could be assessed. Unit 52 is a General Electric MS 7001C simple-cycle, single-shaft, heavy duty gas turbine, rated at 70.8 MW nominal electrical output. This gas turbine may use either natural gas or distillate oil fuels. The test program was conducted using oil fuel. Water injection was used for NOx control. A water-to-fuel ratio of 0.42 reduced NOx by 58% from baseline levels. The unit heat rate showed about 2% change in going from baseline to controlled (for NOx) operation. Test results indicate that using water injection for NOx control in this unit reduced NOx and showed little effect on other emissions. Water injection reduced operating efficiency.

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ABSTRACT

This test report describes the methods and results of an environmental assessment test program conducted at Houston Lighting and Power's T. H. Wharton Generating Station, Unit 52. The purpose of the test program was to measure changes in emissions as a result of applying NO_x controls. Emissions of trace elements, organic materials, sulfur species, and the criteria pollutants, SO_2, NO_x, CO, and particulate matter, were measured. Comparisons of these emissions under normal operating conditions and controlled (for NO_x) operating conditions were then made. Source operating data were also analyzed so that changes in operating parameters and efficiency could be assessed.

Unit 52 is a General Electric MS 7001C simple-cycle, single-shaft, heavy duty gas turbine rated at 70.8 MW nominal electrical output. This gas turbine may use either natural gas or distillate oil fuels. The test program was conducted using oil fuel.

Water injection was used for NO_x control. A water-to-fuel ratio of 0.42 resulted in a 58 percent reduction in NO_x from baseline levels. Changes in other emissions were within the limits of the analyses.

Operating efficiency decreased with water injection. The unit heat rate showed approximately 2 percent change in going from baseline to controlled (for NO_x) operation.

The test program concludes that using water injection for NO_x control in this unit reduced NO_x and showed little effect on other emissions. Water injection implementation did reduce operating efficiency.

ACKNOWLEDGEMENT

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SECTION 1

INTRODUCTION

This report is part of a series of test reports resulting from the experimental testing task of the "Environmental Assessment of Stationary Source NO_x Control Technologies" Program (NO_x EA), being performed under Environmental Protection Agency (EPA) contract 68-02-2160. The NO_x EA is a 3-year program to: (1) identify the multimedia environmental impact of stationary combustion sources and combustion modification NO_x controls; and (2) identify the most cost-effective environmentally-sound NO_x controls for attaining and maintaining current and projected NO_2 air quality standards to the year 2000.

During the first year of the NO_x EA a preliminary environmental assessment (Reference 1) concluded that emissions and operating data needed to perform adequate process engineering and environmental assessment activities were severely lacking in several key areas. Most noteworthy was the virtual absence of data on noncriteria flue gas emissions and liquid and solid effluents. In response to these identified data needs, seven field test programs were initiated. Source selection was based on a source/control priority listing developed in the preliminary environmental assessment. These test programs were designed to provide information on changes in emissions and operation due to NO_x controls. The NO_x EA Field Test Program is outlined in Table 1-1.

The test program documented in this report was conducted on Unit 52 of the T. H. Wharton Generating Station of the Houston Lighting and Power Company in Houston, Texas from April 21-24, 1978. Unit 52 was selected because its design is typical of large scale simple cycle utility gas turbines equipped with water injection and because of the possibility of collaborating with the engine manufacturer in detailed process evaluation tests. Unit 52 is a General Electric Model MS 7001C simple-cycle, single-shaft, heavy duty gas turbine rated at 70.8 MW nominal electrical

TABLE 1-1. NO_x EA FIELD TEST PROGRAM

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Coal-fired Utility Boiler	Kingston #6; 180 MW tangential; twin furnace, 12 burners/furnace, 3 elevations; cyclone, 2 ESP's for particulate control	Baseline Biased Firing (2) BOOS (2)	Continuous NO_x, SO_2, CO, CO_2, O_2 Inlet to 1st ESP: -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Outlet of 1st ESP: -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Bottom ash Hopper ash (1st ESP, cyclone) Fuel Operating data	TVA	Complete, August 1977
Coal-fired Utility Boiler	Crist #7, 500 MW opposed wall fired; 24 burners, 3 elevations; ESP for particulate control	Baseline BOOS (2)	Continuous NO_x, CO CO_2, O_2 ESP inlet -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) ESP outlet -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Bottom ash ESP hopper ash Fuel Operating data Bioassay	Exxon	Complete, June 1978
Oil-fired Utility Boiler	Moss Landing #6, 740 MW opposed wall fired; 48 burners, 6 elevations	Baseline FGR FGR + OFA	Continuous NO_x, CO, CO_2, O_2 Flue gas -- SASS -- Method 5 -- Method 8 -- Gas grab (C_1-C_6 HC) Fuel Operating data Bioassay	New test start	Complete, September 1978

EE-073

TABLE 1-1. Continued

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Coal-fired Industrial Boiler	Traveling grate spreader stoker, 38 kg/s (300,000 lb/hr); ESP for particulate control; wet scrubber for SO_x control	Baseline LEA + high OFA	Continuous NO_x, CO, CO_2, O_2 Boiler exit: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) ESP outlet: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) Bottom ash Cyclone hopper ash Fuel Operating data	KVB	Complete, October 1977
Coal-fired Industrial Boiler	Traveling grate spreader stoker, 25 kg/s (200,000 lb/hr) ESP for particulate	Baseline LEA + High OFA	Continuous NO_x, CO, CO_2, O_2 Boiler exit: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) ESP Outlet: -- SASS -- Method 5 -- Shell-Emeryville -- Gas grab (C_1-C_6 HC) Bottom ash ESP hopper ash Fuel Operating data Bioassay	KVB	Complete, February 1978
Oil-fired Gas Turbine	T.H. Wharton Station, 60 MW GE MS 7001 C machine	Baseline water injection to meet proposed NSPS	Continuous NO_x, CO, CO_2, O_2 Exhaust gas: -- SASS -- Method 5 -- Method 8 Fuel Water Operating data	General Electric	Complete, April 1978

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TABLE 1-1. Concluded

Source Category	Description	Test Points (Unit Operation)	Sampling Protocol	Test Collaborator	Status
Oil-fired Residential Heating Unit	Blue Ray low NO_x furnace, Medford, New York	Continuous Cycling	Continuous NO_x, CO, CO_2, O_2 Flue gas: -- SASS -- Method 5 -- Method 8 Fuel	New test start with EPA/IERL-RTP	Complete, November 1977

EE-073

output. Through the cooperation of the Houston Lighting and Power Company and the General Electric Company, this unit was made available for testing in the NO_x EA Field Test Program.

The test program at the T. H. Wharton Station consisted of a baseline (normal operation) test and a test with water injection being used for NO_x control. The test program results will be used in both process analysis and source assessment modeling, conducted as part of the Environmental Assessment and Process Engineering Task of the NO_x EA.

SECTION 2
PLANT DESCRIPTION

The field tests were conducted on Unit 52 of the T. H. Wharton Generating Station of the Houston Lighting and Power Company in Houston, Texas. Unit 52 is a General Electric Model MS 7001C (Figure 2-1) simple-cycle, single-shaft, heavy-duty stationary gas turbine rated at 70.8 MW nominal electrical output and is one of six such units at the Wharton Station. The Station also has eight GE 7001B combined cycle units, one Westinghouse 15 MW unit and two conventional steam boilers producing a total rated electrical output of 280 MW.

Unit 52 is fired with No. 2 distillate fuel oil with 0.11 percent sulfur by weight and approximately 46.054 x 10^3 kJ/kg (19,800 Btu/lb) heat content. Table 2-1 lists the rated operating parameters of the unit. There is no flue gas cleaning equipment on a turbine of this type due to the clean fuel used and the unit's inherent efficient combustion. Unit 52 is, however, equipped with a water injection system used to control the formation of NO_x within the combustion chambers. NO_x formation is repressed when atomized water is injected directly into the primary zone of the combustor resulting in reduced flame temperatures. The degree of NO_x control is adjusted by altering the quantity of water injected -- the more water injected the greater the degree of control. The first test on Unit 52, a baseline test, was run with no water injected. The second test was run while 2.52 l/sec (40 gpm) water was being injected. This corresponds to a water to fuel mass ratio of approximately 0.42, a ratio sufficiently high to bring NO_x emissions to within 75 ppm at 15 percent O_2 which is the level of the proposed New Source Performance Standards.

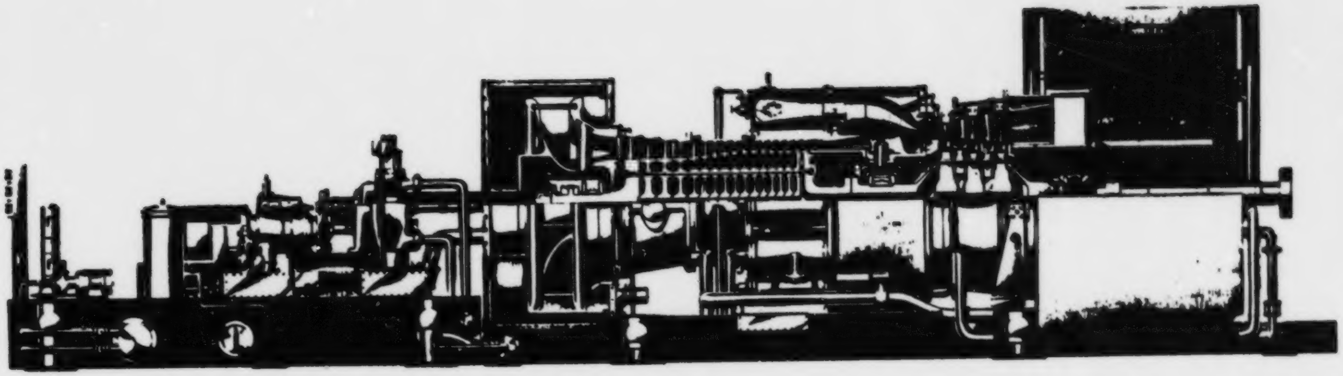


Figure 2-1. Model series 7001 simple-cycle, single-shaft heavy-duty gas turbine.

TABLE 2-1. UNIT 52 RATED OPERATING PARAMETERS

Output power	70.8 MW
Overall pressure ratio	10.5
Heat rate	11.44 MJ/kWh (10,847 Btu/Kwh)
Air flow	268 kg/sec (592 lb/sec)
Fuel flow	5.2 kg/sec (11.5 lb/sec)

SECTION 3
SAMPLING AND ANALYSIS METHODOLOGIES

The sampling and analysis procedures used in the test program closely follow the procedures recommended in the IERL-RTP Level 1 Environmental Assessment Procedures Manual (Reference 2). The following subsections will contain notations of where the procedures differ significantly from the standard methods. Level 1 testing, according to EPA's phased environmental assessment approach, is for screening purposes. Through chemical and biological tests potential problem areas and needs for further analysis are identified. Furthermore, Level 1 testing provides the basis for setting priorities for discharge streams, components, and classes of materials for further consideration in an overall environmental assessment. Thus, the results of the sampling and analysis procedures used in Level 1 are semiquantitative, yielding an accuracy factor of ± 2 to 3.

All analyses for trace elements, organic species, particulates and sulfur species in the Method 5/8 and SASS trains and water samples were performed in the Acurex analytical laboratory. Commercial Testing and Engineering Company analyzed the fuels and the bioassay analyses were performed by Litton Bionetics, Incorporated.

3.1 SAMPLING PROTOCOL

In order to effectively evaluate how emissions of compounds and pollutant species are affected by the use of water injection, all influent and effluent streams must be characterized during the baseline and water injection tests. The following streams on Unit 52 were sampled:

- Water feed (water injection system)
- Fuel feed
- Exhaust gas

Ambient air was not sampled. Descriptions of the specific sampling methods are given in the following paragraphs. Figure 3-1 shows the duct configuration and the location of the sampling ports.

3.1.1 Feed Streams

Water Feed

Samples of the demineralized feed water from the water injection purification system were periodically sampled throughout the five hour duration of the NO_x control test. Samples were tapped off the inlet lines preceeding the combustor section and then composited into one integrated sample for each run.

Fuel Feed

Fuel oil samples were obtained for both tests. Samples were tapped off the fuel inlet lines, collected throughout the test period and finally composited into one integrated sample for each test. Sampling of the fuel feed commenced one hour into the test run, then approximately once for each 90 minute period throughout the test.

3.1.2 Flue Gas

The flue gas was monitored on a continuous basis during both test runs for O_2, CO_2, NO, total NO_x, total unburned hydrocarbons and CO. The continuous monitoring was provided by General Electric (GE) personnel and equipment. Table 3-1 lists the instrumentation used by General Electric. All sample lines were of Teflon construction and heated to 450 K (350°F) to assure the integrity of all sampled species. The sample flow was filtered to remove particulate matter and then split into two streams. One stream supplied the nitrogen oxides instrument and the total hydrocarbon monitor, while the other supplied the nondispersive infrared (NDIR) instruments and the paramagnetic oxygen analyzer. The latter stream was further conditioned in a saturator and refrigerated dryer before connecting to the CO_2, CO and O_2 analyzers. All monitors were frequently zeroed and calibrated with certified gases.

All continuous gaseous sampling was done through a single point probe located in the center of the exhaust duct approximately lm (40 inches) upstream of the main row of sampling ports used for the SASS and Method 5/8 sampling.

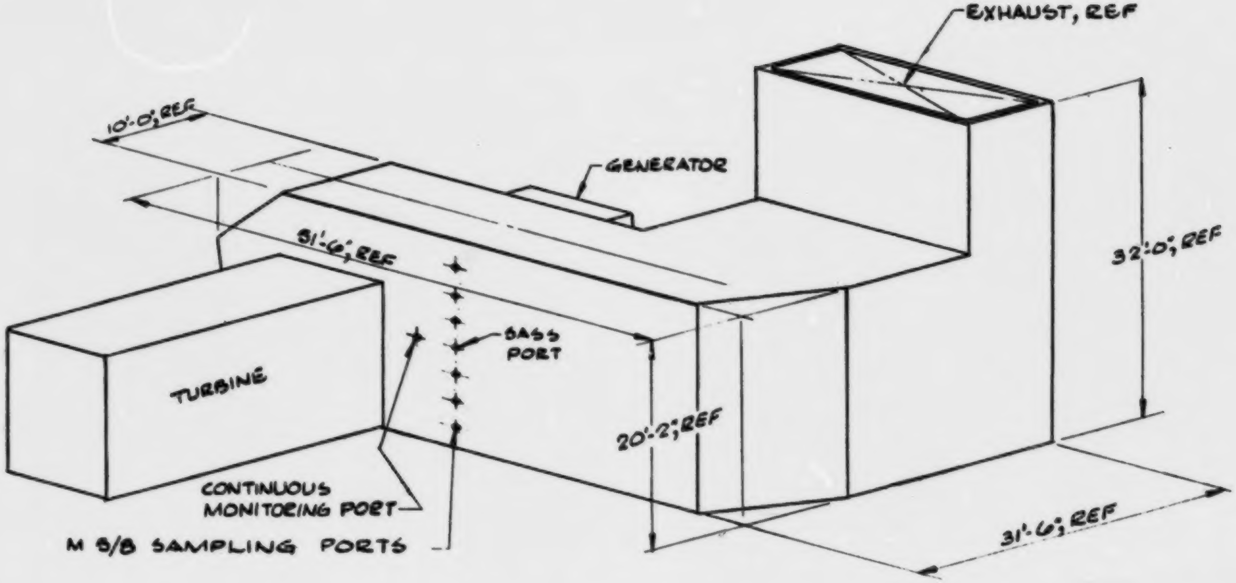

EXHAUST, REF
10'-0", REF
GENERATOR
31'-6", REF
32'-0", REF
SASS PORT
TURBINE
20'-2", REF
CONTINUOUS MONITORING PORT
M 5/5 SAMPLING PORTS
31'-6", REF

Figure 3-1. Exhaust duct configuration and sampling location.

TABLE 3-1. INSTRUMENTATION USED BY GENERAL ELECTRIC

Instrument	Technique	Measuring Range
Unburned hydrocarbons: Beckman Model 402	Flame ionization detector	5 ppm - full scale to 25% - full scale
NO and NO_2: Beckman 955	Chemiluminescence	0 - 10 ppm 0 - 1,000 ppm 0 - 25 ppm 0 - 2,500 ppm 0 - 100 ppm 0 - 10,000 ppm 0 - 250 ppm
O_2: Beckman Model F3	Paramagnetic	0 - 15% 13% - 18% 16% - 21% 0 - 25%
CO: Beckman 315B	Nondispersive infrared	0 - 50 ppm 0 - 200 ppm 0 - 500 ppm
CO_2: Beckman 364	Nondispersive infrared	0 - 5% 0 - 10% 0 - 15%

Particulate and Sulfur Species

Particulate and sulfur species in the flue gas were collected simultaneously with one sampling train -- a combined EPA Method 5 and Method 8 train. Such a system collects particulate samples on a filter heated to 394 K (250°F) in a conventional Method 5 arrangement. But rather than the conventional Method 5 water filled impinger train, the modified train employs a Method 8 impinger train containing isopropanol to remove SO_3 and hydrogen peroxide to remove SO_2. Particulate sulfate (SO_4) is also collected with this system. One run was completed for each test.

C_1-C_6 Hydrocarbons

Flue gas grab samples were collected in evacuated glass grab flasks. These samples were chromatographed onsite to determine C_1 to C_6 hydrocarbon compounds. A Carle Model 8500 portable gas chromatograph with a flame ionization detector was used for this analysis.

Source Assessment Sampling System

A Source Assessment Sampling System (SASS) train was used to sample the gas turbine exhaust gas. The SASS train was conventional in every way except that cyclones were not used to classify the particulate by size. A single fiberglass mat filter was used to collect the small amounts of particulate produced. A special oil cooled probe was used to maintain the sample tube temperature at 394 K (250°F). This SASS train arrangement generates the following samples:

Particulate: filter 99.99 percent efficient for particulate greater than 0.2 m.
Vapor phase: 1) XAD-2 porous polymer resin sorbent cartridge
2) Aqueous condensate
3) Hydrogen peroxide impinger
4) Ammonium persulfate-silver nitrate impingers

These samples were analyzed for trace elements and organic species to give both vapor and condensed phase composition.

A schematic of the SASS train is shown in Figure 3-2. The analysis protocol is given in Figure 3-3.

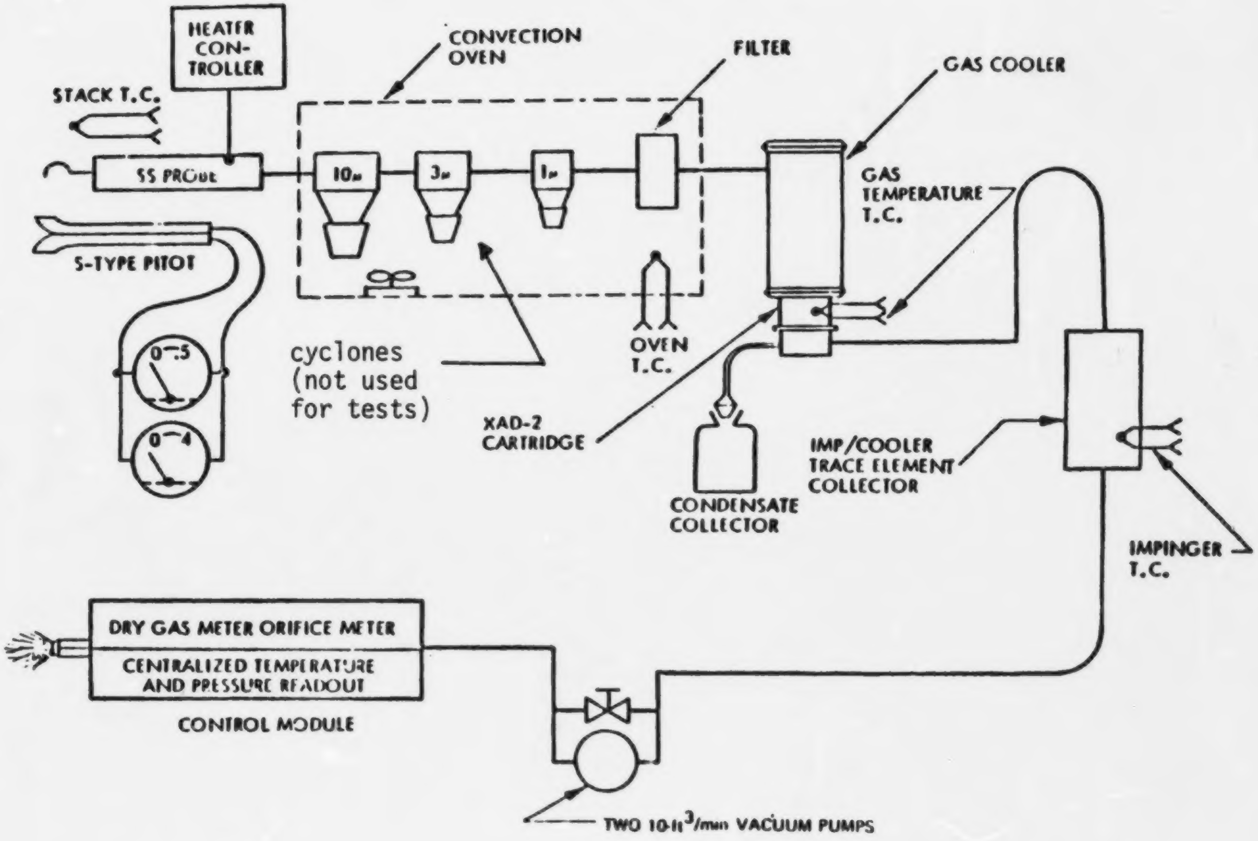
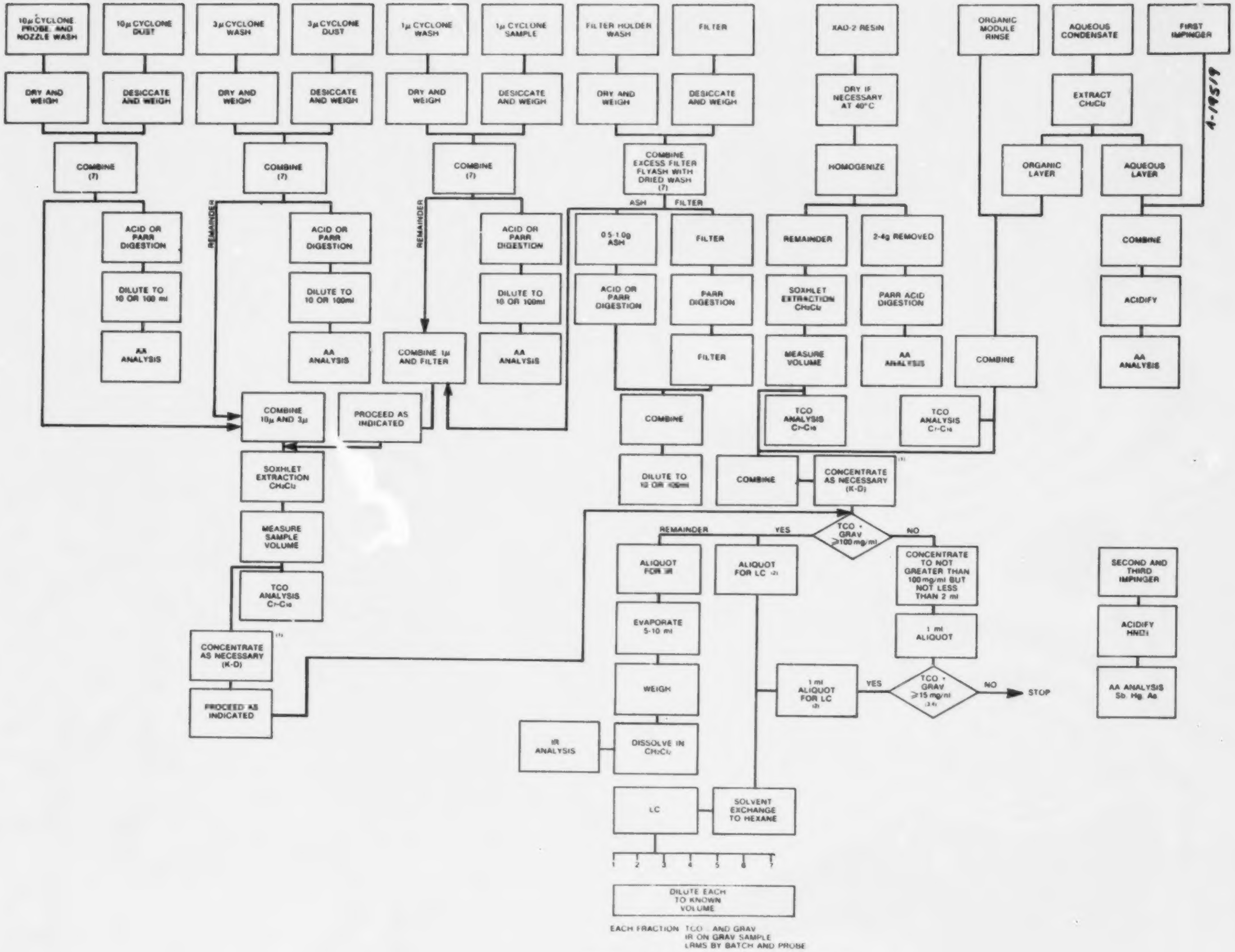

HEATER CON-TROLLER
STACK T.C.
SS PROBE
S-TYPE PITOT
0–.5
0–4
CONVECTION OVEN
10μ
3μ
1μ
cyclones (not used for tests)
FILTER
OVEN T.C.
XAD-2 CARTRIDGE
GAS COOLER
GAS TEMPERATURE T.C.
CONDENSATE COLLECTOR
IMP/COOLER TRACE ELEMENT COLLECTOR
IMPINGER T.C.
DRY GAS METER ORIFICE METER
CENTRALIZED TEMPERATURE AND PRESSURE READOUT
CONTROL MODULE
TWO 10-ft3/min VACUUM PUMPS

Figure 3-2. Source Assessment Sampling System (SASS) schematic.


10μ CYCLONE PROBE, AND NOZZLE WASH
10μ CYCLONE DUST
3μ CYCLONE WASH
3μ CYCLONE DUST
1μ CYCLONE WASH
1μ CYCLONE SAMPLE
FILTER HOLDER WASH
FILTER
XAD-2 RESIN
ORGANIC MODULE RINSE
AQUEOUS CONDENSATE
FIRST IMPINGER
DRY AND WEIGH
DESICCATE AND WEIGH
DRY IF NECESSARY AT 40°C
EXTRACT CH₂Cl₂
COMBINE (7)
COMBINE EXCESS FILTER FLYASH WITH DRIED WASH (7)
HOMOGENIZE
ORGANIC LAYER
AQUEOUS LAYER
REMAINDER
ASH
FILTER
ACID OR PARR DIGESTION
DILUTE TO 10 OR 100 ml
AA ANALYSIS
0.5-1.0g ASH
PARR DIGESTION
2-4g REMOVED
SOXHLET EXTRACTION CH₂Cl₂
PARR ACID DIGESTION
MEASURE VOLUME
COMBINE
ACIDIFY
COMBINE 1μ AND FILTER
COMBINE 10μ AND 3μ
PROCEED AS INDICATED
TCO ANALYSIS C₇-C₁₆
MEASURE SAMPLE VOLUME
CONCENTRATE AS NECESSARY (K-D) (1)
TCO + GRAV ≥100 mg/ml
YES
NO
ALIQUOT FOR IR
ALIQUOT FOR LC (2)
CONCENTRATE TO NOT GREATER THAN 100 mg/ml BUT NOT LESS THAN 2 ml
1 ml ALIQUOT
EVAPORATE 5-10 ml
WEIGH
1 ml ALIQUOT FOR LC (2)
TCO + GRAV ≥15 mg/ml (3,4)
STOP
IR ANALYSIS
DISSOLVE IN CH₂Cl₂
LC
SOLVENT EXCHANGE TO HEXANE
1 2 3 4 5 6 7
DILUTE EACH TO KNOWN VOLUME
SECOND AND THIRD IMPINGER
ACIDIFY HNO₃
AA ANALYSIS Sb, Hg, As
EACH FRACTION TCO, AND GRAV
IR ON GRAV SAMPLE
LRMS BY BATCH AND PROBE
COMBINED FRACTIONS 2 AND 3 GC/MS ANALYSIS FOR 12 POM S(4)

4-19519

Figure 3-3. SASS analysis protocol.

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3.2 ANALYSIS PROTOCOL

Table 3-2 lists the analyses performed on the samples collected during both tests. Descriptions of these analyses are given in the following paragraphs.

In addition, machine operating data were collected by General Electric personnel. Sufficient data were taken during both tests so that airflow rates and the operating condition of the machine could be established. A detailed field test report submitted by General Electric is contained in Appendix G. In summary, GE treats operating data, information on gaseous emissions, fuel composition, machine geometry and internal flow splits, using a data analysis program which calculates machine operational characteristics. Table 3-3 illustrates the kind of information that can be obtained. This program proved an excellent means of crosschecking actual flue gas measurements as well as checking calculation methods against each other.

3.2.1 Inorganic Analysis

Trace element analyses for 23 selected trace elements were performed on the fuel, injected water, flyash, SASS XAD-2 and SASS impinger solutions. The procedure used to determine each trace element is outlined in Appendix H. Proximate and ultimate analyses were done on the fuel samples.

3.2.2 Organic Analysis

Organic analyses were performed in accordance with EPA Level 1 protocol (Reference 2). These analyses included C_1-C_6 hydrocarbons in the flue gas, organic material condensed on the ash samples, and organic material caught in the XAD-2 sorbent trap and condensate trap.

3.2.3 Bioassay

Bioassays were performed on the SASS train XAD-2 extract sample from the water injection test. Microbial mutagenesis and cytotoxicity assays were performed by Litton Bionetics, Incorporated.

TABLE 3-2. SAMPLE ANALYSIS

Test/Analysis	Baseline no water injection	Low NO_x with water injection
Fuel		
Proximate and ultimate	X	X
Trace elements	X	X
Water		
Trace elements		X
Organic material		X
SASS train - outlet		
Trace elements	X	X
Organic material	X	X
Method 5/8 -- outlet		
Particulate	X	X
Sulfur species	X	X
Flue gas		
O_2, CO_2, NO_x, NO, CO	X	X
and total unburned hydrocarbons	X	X
C_1-C_6 hydrocarbons	X	X

TABLE 3-3. GENERAL ELECTRIC CALCULATED OPERATING DATA[a]

Calculation Method	Measured	Calculated
Factory test flow	Fuel flow and composition, airflow during factory test, inlet guide vane position, ambient conditions	Machine airflow, O_2, CO_2, water in exhaust, turbine inlet temperature.
Choked flow	Compressor discharge pressure and temperature, first stage nozzle area, fuel flow and composition.	Machine airflow, O_2, CO_2, H_2O, turbine inlet temperature.
Oxygen concentration	O_2, fuel flow and composition	Machine airflow, CO_2, H_2O, turbine inlet temperature.
CO_2 concentration	CO_2, fuel flow and composition	Machine airflow, O_2, H_2O, turbine inlet temperature.

[a] See Appendix G

SECTION 4
TEST PROGRAM RESULTS

Data from the test program provided information on unit operation, effluent gaseous composition, particulate emissions, trace element emissions, sulfur species emissions and organic material emissions.

4.1 UNIT OPERATION

Unit 52 operated under steady-state conditions at rated continuous load and with operating parameters nominally the same for both the baseline (no water injection) and the NO_x control (with water injection) test. The load for each test was approximately 62 MW electrical generator output. Table 4-1 lists the process operating conditions and parameters during each test. The only significant difference between Test 1 and Test 2 is that Test 2 had water injection while Test 1 did not. Since it is fairly easy to duplicate engine operating conditions in a gas turbine, one can be reasonably confident in comparing emissions from tests where only the one variable, water injection rate, was changed.

The operating variable readings were recorded on an hourly basis throughout the tests. The results shown in Table 4-1 are an average of those values. The actual data sheets can be found in Appendix G.

One of the most significant penalties resulting from the use of water injection for NO_x control is the reduction in unit thermal efficiency or increased heat rate manifested as increased fuel consumption. As indicated in Table 4-1, the unit heat rate increased 2.4 percent with water injection at a water/fuel ratio equal to 0.42. This is because a portion of the fuel is required to vaporize the injected water. These effects on heat rate and fuel consumption are quite typical (Reference 3). Most users have reported heat rate penalties ranging from 2 to 5 percent, depending on the water to fuel ratio.

TABLE 4-1. UNIT 52 -- OPERATING CONDITIONS

	Baseline	Injection
Ambient barometric pressure - mm Hg (in. Hg)	755 (29.74)	756 (29.79)
Ambient temperature -- dry bulb -- K (°F)	295 (71.2)	301 (82.0)
Relative humidity	83.6	58.7
Compressor discharge pressure P_{CD} -- kpa (psia)	915 (132.7)	901 (130.7)
Compressor discharge temperature T_{CD} -- K (°F)	593 (607)	602 (624)
Speed (rpm)	3600	3600
Inlet guide vane angle (IGV degrees)	77	77
Load (MW)	61.9	61.5
Turbine exhaust temperature -- K (°F)	809 (997)	813 (1000)
Water injection rate -- liters/sec and (gpm)	0	2.52 (40)
Water/fuel ratio	0	0.42
Fuel temperature -- K (°F)	295.4 (71.7)	298 (76.4)
Fuel flow -- liters/sec and (gpm)	5.93 (94.0)	6.03 (95.6)
Atomizing air pressure -- kpa (psia)	1372 (199)	1372 (199)
Atomizing air temperature -- K (°F)	473 (392)	471 (387)
Combustion efficiency (%)	99.9	99.9
Exhaust flow -- m^3/s (10^6 SCFH)	205.4 (26.14)	200.9 (25.52)
Compressor inlet flow -- kg/s (lbm/sec)	253 (556.7)	255.7 (562.7)
Fuel/air ratio	0.0190	0.0196
Heat rate -- MJ/kWh (Btu/Kwh - based on LHV)	12.55 (11,892)	12.84 (12,173)

As noted in Section 3.2, GE personnel recorded operating data and monitored unit operation throughout the test program. In addition GE also evaluated recorded data using an in-house data analysis code. This program can be used to calculate inlet airflow and exhaust gas flow (in addition to other parameters -- see Table 3-3) using gaseous emissions data and other operating information. Four different calculational modes are possible, as outlined in Table 3-3. Calculated exhaust gas flowrates for each test, using the program, are listed in Table 4-2 for each of the calculation methods. Agreement among the methods is excellent (within one percent). Also shown in Table 4-2 are measured exhaust gas flowrates obtained by performing an EPA Method 5 velocity traverse across the exhaust duct. As indicated, measured rates are approximately 55 percent greater than calculated rates. This was not unexpected, though. The exhaust duct configuration was such that gas flow obstructions (i.e., bends) were very close to the sampling location, thus accurate velocity measurements were very difficult to obtain. In an attempt to equalize the effects of a poor sampling location, 42 sampling points were sampled. Nevertheless, measured gas flowrates were still unreasonably high due to the highly variable velocity readings.

Thus all exhaust flowrate values reported herein, including those noted in Table 4-1, are calculated values, averaged over the four possible calculational methods.

4.2 FUEL ANALYSIS

Duplicate proximate and ultimate fuel analyses were performed by General Electric and Commercial Testing and Engineering (CT&E). General Electric's results are reported in Appendix G. CT&E's analysis is reported in Appendix A. Results from both analyses were very similar and typical of distillate fuel oil. In addition, a trace element analysis of the fuel oil was performed as part of the mass balance and reported in Concentration and mass flowrate units in Appendices B-E.

4.3 EXHAUST GAS EMISSIONS

Exhaust emissions were tested for gaseous species, particulate emissions, sulfur species, trace elements and organic material emissions. Gaseous species were measured by General Electric personnel on a continuous basis throughout both tests. A combined EPA Method 5/8 train

TABLE 4-2. CALCULATED AND MEASURED EXHAUST GAS FLOWRATES -- m^3/s (10^6 SCFH)

Test No.	GE -- Calculated Values[a]					
	Factory Test Flow	Choked Flow	Oxygen Concentration	CO_2 Concentration	Average	Measured
1	203.8 (25.9244)	205.3 (26.1206)	207.2 (26.3644)	205.8 (26.1828)	205.4 (26.1481)	316.4 (40.2632)
2	199.3 (25.3136)	201.0 (25.5280)	202.5 (25.7149)	220.5 (27.9991)	200.9 (25.5188[b])	311.4 (39.6247)

[a] See Appendix G for explanation of calculations

[b] Exhaust gas flowrate calcualted by the CO_2 concentration scheme not included in average. CO_2 values believed to be affected by moisture in flue gas.

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was used to simultaneously sample particulates and sulfur species. A Source Assessment Sampling System (SASS) was used to collect samples for analysis of trace elements and organic material. This section presents the results of these analyses.

4.3.1 Gaseous Emissions

Total NO_x, NO, O_2, CO_2, CO and total unburned hydrocarbons (UHC) were measured at a single point in the exhaust duct. Supporting tests conducted by General Electric, reported in Appendix G, have concluded that emissions of NO_x and O_2 can be reliably and accurately measured from a single sampling point. However, species that are present only in very low concentrations, UHC for example (ppmv <2), require a traverse of the duct when sampling.

Table 4-3 presents gaseous emissions data in a form summarized from the General Electric report in Appendix G. With regard to the proposed New Source Performance Standards (NSPS) for stationary gas turbines, there are two things of importance to note from this information. First, with water injection operating at a water/fuel weight ratio of 0.42, NO_x emissions were reduced by 58 percent from the baseline levels -- from 177.5 to 74.2 ppm at 15 percent O_2 dry. This controlled level is within the NSPS proposed level of 75 ppm. The second item to note is that SO_2 emissions are substantially below the proposed NSPS level of 150 ppmv at 15 percent O_2. The SO_2 values for Unit 52 were calculated directly from the fuel sulfur content assuming 100 percent conversion. The calculated value for SO_2 concentration, which assumes all fuel sulfur is converted to SO_2, is reasonably close to the measured total SO_x emission concentration (within 30 percent) as determined by the Method 8 analysis.

The results of the sulfur species analysis are shown in Table 4-4. The data show that the actual emission levels of sulfur species, as well as the SO_2/SO_3 ratio, are not significantly affected by the use of water injection for NO_x control. Table 4-5 shows the results of a sulfur balance across the gas turbine. The quantity of sulfur recovered in the flue gas was approximately 70 percent of the inlet sulfur. Duplicate fuel oil sulfur analyses gave a sulfur content of approximately 0.11 percent, so inlet sulfur calculations should be correct. Consequently, the source of the inconsistency probably lies in the Method 8 sampling train and subsequent analysis.

TABLE 4-3. GASEOUS EMISSIONS RESULTS -- ppmv at 15 percent O_2 dry

	Baseline	Water Injection
NO_x	175.5	74.2
CO	5.6	8.1
CO_2(%)	4.1	4.3
SO_2 [a]	19.5	20.5
UHC[b]	2.3	3.5

[a] Calculated from fuel sulfur assuming 100 percent conversion to SO_2

[b] ppmv wet as CH_4

TABLE 4-4. SULFUR SPECIES EMISSIONS

Test	Species	Emissions			
		ppmv dry	$\mu g/m^3$	kg/min	$\mu g/J$
Baseline	SO_2	11.7	3.12×10^4	0.385	0.029
	SO_3	1.1	3.48×10^3	0.043	0.003
	SO_4	1.2	4.61×10^3	0.057	0.004
Water Injection	SO_2	12.7	3.37×10^4	0.407	0.030
	SO_3	1.8	6.04×10^3	0.073	0.005
	SO_4 [a]	--	--	--	--

[a] Sample destroyed

TABLE 4-5. SULFUR BALANCE

	Baseline	Water Injection
Sulfur Input		
Fuel feedrate (kg/s)	4.85	4.96
Fuel sulfur content (% by wt.)	0.11	0.11
Total sulfur input (kg/s)	5.33×10^{-3}	5.50×10^{-3}
Sulfur Output		
SO_2 (kg/s)	6.42×10^{-3}	6.78×10^{-3}
SO_3 (kg/s)	0.72×10^{-3}	1.22×10^{-3}
SO_4 (kg/s)	0.95×10^{-3}	
Total sulfur output (kg/s)	3.83×10^{-3}	3.83×10^{-3}
Sulfur recovery at outlet	72%	70%

An increase in emissions of unburned species due to lowered peak flame temperatures, is generally associated with the use of water injection for NO_x control. During the NO_x control test on Unit 52 average emissions of CO and UHC increased 54 and 52 percent respectively. While the increases seem significant, the actual emission concentrations for CO and UHC are still very low (<10 ppm) when water injection is being used.

Onsite analyses of C_1 to C_6 exhaust gas hydrocarbons were conducted for both the baseline and the water injection tests. The test results show that in the baseline test, C_1 to C_6 hydrocarbons were 6.5ppm at 15 percent O_2 wet, characterized as methane. In the water injection test, C_1 to C_6 hydrocarbon emissions were 1ppm at 15 percent O_2 wet, characterized as methane. These results are in general agreement with the total unburned hydrocarbon emissions measured by the continuous monitor.

4.3.2 Particulate Emissions

Particulate emissions for Unit 52 are shown in Table 4-6. As expected from a gas turbine burning distillate fuel oil, particulate emissions were very low, on the order of 0.0037 to 0.0042 kg/s as measured by the EPA Method 5 train. However, correlation between particulate emission rates from the EPA Method 5 train and the SASS train is poor. SASS measurements are almost a factor of 10 lower. This is not surprising however, when one considers that a SASS train is run at a single point in the exhaust duct. In a duct such as that of Unit 52, where flow patterns are irregular due to the duct configuration, particulate matter can be highly stratified. Furthermore, since particulate matter generated in a gas turbine will be very small in size, it will have a greater tendency to stratify with a strong bias to high velocity regions. Since the SASS train is required to operate at a point of average velocity, away from the high velocity regions, particulate capture is expected to be considerably lower in the SASS train than in the Method 5 train, which fully traverses the duct cross section, as this gives representative results.

TABLE 4-6. PARTICULATE EMISSIONS

Test	Particulate Emissions		
	kg/s	μg/Joule	μg/DSCM
Method 5 -- Baseline	4.2×10^{-3}	.019	572
Method 5 -- Water injection	3.7×10^{-3}	.016	509
SASS -- Baseline	0.45×10^{-3}	.002	63
SASS -- Water injection	0.97×10^{-3}	.004	137

While according to the Method 5 measurements, particulate emissions dropped with water injection, the reduction was not significant. Water injection then appears to have little effect on particulate emissions. This is supported by data presented in Reference 3.

4.3.3 Trace Element Characterization and Emissions

Fuel oil, injected water and flue gas samples were collected and analyzed for selected trace elements for the baseline and water injection tests. Grab samples were taken for the oil and water. The flue gas was sampled by using a SASS train. The detailed results of these analyses are presented in Appendices A through F.

The probe wash and the filter have been combined into one sample, as have the aqueous condensate and the first impinger. The XAD-2 cartridge was analyzed independently and the second and third impingers were combined into one sample as outlined in the Level 1 procedures manual (Reference 2).

Solid And Vapor Phase Trace Element Partitioning

The SASS train allows determining both solid phase and gas phase composition. Solid phase species are collected in the probe, cyclones, filter and interconnecting tubing, while the vapor phase species are collected in the organics module or the impinger portions of the SASS train. All SASS train components up to the filter are maintained at 394-478K (250 - 400^{o}F). From there, the flue gas goes to the organics module, where it is cooled to approximately 293 K (68^{o}F) and passed through a cross linked porous polymer resin (XAD-2) cartridge. From this section, two samples are generated: the condensate and the XAD-2 sorbent extract. From the organic module, the flue gas goes through an impinger train. The first impinger contains hydrogen peroxide and the second and third impingers contain silver nitrate-ammonium persulfate solutions. For trace element analysis, the organic module aqueous condensate sample is combined with the hydrogen peroxide impinger sample to form one sample for analysis. Thus three samples representing vapor phase composition are analyzed: the XAD-2, the aqueous condensate and hydrogen peroxide impinger solution, and the combined silver nitrate-ammonium persulfate impinger solution.

To determine whether a particular trace element was concentrated in the solid or vapor phase, trace element flowrates (kg/s) were compared. In order to partition the samples as to whether they were solid or vapor, the following partitioning criterion was used: trace elements were considered to be preferentially concentrated in the vapor phase if their vapor phase concentrations were at least twice their solid phase concentrations. The partitioning results are shown in Table 4-7 for elements where sufficient data to determine partitioning were obtained.

Elemental Mass Balance

A trace element mass balance was performed across the gas turbine system using emissions flowrate data from Appendix C. Table 4-8 presents the results of the mass balance. In general and where sufficient data are available, the element mass balances are within the reliability of the Level 1 sampling and analysis procedures which are assumed to be quantitative within a factor of 2 to 3. Zinc and copper are somewhat outside of these boundaries but not significantly so. Iron, as measured at the outlet for both tests, far exceeds the amount entering the turbine as contained in the fuel oil and injected water. It is possible that the source of this excess iron is rust and scale coming loose from the internal gas turbine ductwork and being captured in the SASS train. The analysis of the fuel for iron was supported by a duplicate analysis performed by GE (Appendix G).

Effects Due to NO_x Control

It appears that the use of water injection to control NO_x emissions has an insignificant effect on trace element emissions. Outlet emissions of all trace elements analyzed remained within a factor of three when comparing the baseline and water injection emission flowrates. Also, water injection has an insignificant effect on trace element emissions with respect to solid/vapor phase partitioning. For those elements where sufficient data were available, the solid/vapor partitioning remained virtually the same.

4.3.4 Organic Analyses

Organic analyses were performed on selected samples according to the EPA Level 1 protocol (Reference 2). Any differences from the Level 1 protocol will be noted in the following discussion. The analytical laboratory data are reported in Appendix F.

As recommended by Level 1 analysis procedures the samples were first extracted with methylene chloride in a Soxhlet apparatus. A Total Chromatographable Organic (TCO) and a gravimetric (GRAV) analysis were then performed on the sample extracts. This analysis separates each

TABLE 4-7. TRACE ELEMENT PARTITIONING -- SOLID PHASE/VAPOR PHASE

	Baseline	Water Injection
Arsenic	X.	V
Barium	X	V
Beryllium	X	V
Cadmium	V	V
Chromium	V	EQ
Copper	V	V
Iron	V	V
Lead	V	EQ
Manganese	X	V
Mercury	V	X
Nickel	V	S
Thallium	X	V
Vanadium	V	V
Zinc	X	S

EQ -- Material partitioned equally between vapor and solid phase
S -- Material preferentially concentrated in solid phase
V -- Material preferentially concentrated in vapor phase
X -- Insufficient data

TABLE 4-8. TRACE ELEMENT MASS BALANCE -- OUTLET (g/min)/INLET(g/min)

	Baseline	Water Injection
Boron	<1	1.2
Cadmium	.62	--
Chromium	.24	>3
Cobalt	--	<1
Copper	>5	>7
Iron	>100	>100
Lead	.26	44
Mercury	.16	1.4
Nickel	>.7	>2
Selenium	<.1	--
Vanadium	>.3	>.6
Zinc	3.5	4.6

sample extract into two separate samples having definite boiling point ranges. The TCO fraction contains species with boiling points in a range from 373 K to 573 K. Those species with boiling points above 573 K are contained in the gravimetric sample.

An infrared spectrophotometric (IR) analysis was also performed on the total sample extracts. This aided in the identification of functional organic groups within the complex sample mixture. The organic material in the sample extract was not sufficient to warrant separation by liquid chromatography with further analyses of the fractions eluted. The total sample extracts were analyzed by gas chromatography-mass spectrometry (GCMS) for specific polycyclic organic molecules and priority pollutants.

C_1 to C_6 hydrocarbon compounds were analyzed onsite by gas chromatography. The same set of organic analyses was performed on the samples from the baseline and the water injection test. A discussion of the analytical results follows.

Total Chromatographable Organics (TCO) and Gravimetric Analyses (GRAV) of Organic Extracts

Total Chromatographable Organics (TCO) and Gravimetric Analyses (GRAV) were performed on the XAD-2 resin extracts from the baseline and water injection tests. The extract samples were combined with the organic portion of the sorbent module condensate. The results from these analyses are shown in Table 4-9. Three conclusions can be drawn from these results. First, virtually all of the organics in the flue gas can be found in compounds with the boiling point ranging from 373 K to 573 K. Second, there is little effect on the distribution of compounds, with regard to the boiling point, between the baseline and water injection test. Third, the use of water injection has a very small effect on the total amount of organics in the sample extract, decreasing the quantity by approximately 6 percent.

Infrared Spectra of Total Extracts

The results of the infrared spectral analyses done on the total XAD-2 sample extracts for the baseline and water injection test are shown in Tables 4-10 and 4-11 respectively. Comparison of the wave numbers and assignments (as well as the spectra themselves) indicate that the organics were almost identical for both tests. Both spectra indicate that the

TABLE 4-9. TCO AND GRAV ANALYSES RESULTS OF THE XAD-2 EXTRACT

Test	Sample Type	Gravimetric Result (mg)	TCO Result (mg)	Total Organics in Extract (mg)	Total Organics Concentration (mg/m^3)
Baseline	XAD-2 extract	0.6	27.5	28.1	1.3[a]
Water injection	XAD-2 extract	<0.1	26.3	26.3	1.1[b]

[a] Based on sample volume = 20.9 m^3
[b] Based on sample volume = 23.2 m^3

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principal constituents were an ester or a carboxylic acid and an alcohol. Unsaturated compounds and/or aromatic groups were also present although the intensity of the bands suggest that they may not be part of the principal constituents.

Gas Chromatography-Mass Spectrometry (GCMS) Analysis of Total Extracts

Liquid column separation and low resolution mass spectrometry were not performed on the sample extracts because an insufficient sample volume remained after concentration. However, the sample extracts were analyzed by GCMS. Specific compounds were identified and quantified with this technique.

Tables 4-12 and 4-13 show the GCMS results for the baseline and water injection tests. Table 4-14 lists the specific compounds which were analyzed with the GCMS.

4.3.5 Bioassay

Mutagenicity and cytotoxic evaluations were performed on the XAD-2 extract sample from the water injection test. Results from the Ames salmonella/microsome plate test show the sample nonmutagenic. Results of the cytotoxicity assay indicate the extract has low toxicity to WI-38 human cells and that the viability index showed an EC50 value would be obtained at approximately 152 liters gas/ml. Complete results and supporting data are located in Appendix I.

4.3.6 Conclusions

The use of water injection for NO_x control on Unit 52 appears to have little effect on organic emissions. Neither the total organics, as reported in the TCO and GRAV analyses, nor the species and classes of organics charged significantly from the baseline test to the water injection test.

TABLE 4-10. INFRARED SPECTRA ANALYSIS RESULTS -- XAD-2 EXTRACT, BASELINE TEST

Wave Number (cm^{-1})	Intensity[a]	Assignment	Comments
3400-3500	S	O-H	Broad peak
2960, 2920, 2850	S	C-H	Aliphatic
1720-1700	S	C=O	Carbonyl possibly ester
1600	W	C=C	Unsaturated, aromatic
1450	M	$-CH_3$ bending	Methyl groups
1370	M		Possibly methyl
1260	S	-O- bending	Ether/ester
1070-1090	M	Unassigned	Broad peak
800	W	Unassigned	Possibly aromatic Substitution bands
710	W	Unassigned	Possibly aromatic Substitution bands

[a] Intensity: S - strong, M - medium, W - weak

TABLE 4-11. INFRARED SPECTRA ANALYSIS RESULTS -- XAD-2 EXTRACT, WATER INJECTION TEST

Wave Number (cm^{-1})	Intensity[a]	Assignment	Comments
3400-3500	S	O-H	Broad peak
2960, 2920, 2850	S	C-H	Aliphatic
1690-1720	S	C=O	Carbonyl broad
1600	W	C=C	Unsaturated, aromatic
1450, 1460	M	$-CH_3$	Methyl band
1380	M		Possibly methyl
1260	S	-O-	Ether/ester
1070-1100	S	Unassigned	Broad peak
800	M	Unassigned	Possibly aromatic Substitution bands
710, 700	M	Unassigned	Possibly aromatic Substitution bands

[a] Intensity: S - strong, M - medium, W - weak

TABLE 4-12. GCMS RESULTS -- XAD-2 EXTRACT -- BASELINE TEST

Compound	Concentration ($\mu g/m^3$)[b]
Bis(2-ethylhexyl)phthalate[a]	1.0
Other phthalates	1.0
Phenanthrene/anthracene[a]	0.5
Diphenyl ether	0.5
Phenol	1.0

[a] Confirmed by comparison with standard
[b] Based on sample volume = 20.9 m^3

TABLE 4-13. GCMS RESULTS -- XAD-2 EXTRACT -- WATER INJECTION TEST

Compound	Concentration ($\mu g/m^3$)[b]
Bis(2-ethylhexyl)phthalate[a]	1.0
Other phthalates	1.0
Phenanthrene/anthracene	1.0
Fluoranthene	0.5
Pyrene	0.5
Terphenyl	5.0
Diphenylcyclohexane (2 isomers)	10.0
Phenol	1.0
Naphthalene	1.0

[a] Based on sample volume = 23.2 m^3

TABLE 4-14. COMPOUNDS SCREENED FOR IN GCMS ANALYSIS OF XAD-2 EXTRACTS

Compound	Representative m/e Values	Compound	Representative m/e Values
7,12 dimethyl benz (a) anthracene	256	Methylnaphthalene	42,127
Dibenz (a,h) anthracene*	278	Biphenyl	154
Benzo (c) phenanthrene	228	Phthalic Anhydride	148,104
3-methyl cholanthrene	268	Nitronaphthalene	173,115
Benzo (a) pyrene*	252	Dibenzothiophene	184,139
Dibenzo (a,H) pyrene	302	Alkanes	57,71
Dibenzo (a,i) pyrene	302	Decalin	67,138
Dibenzo (c,g) carbozole	267	Anthracene*	178
Fluoranthene*	202	Phenanthrene*	178
Pyrene*	202		
Anthanthrene	276		
Benz (a) anthracene*	228		
Benzo (g,h,i) perylene*	276		
Benzo (e) pyrene	252		
Perylene	252		
Naphthalene	128		
Acenaphthylene	152		
Acenaphthene	154		
Fluorene	166		
Diphenyl ether	170		
Dibenzofuran	168		
Fluorenone	180,152		
Naphthoquinone	158,130		
Xanthone	196,168		
Xanthene	182,181		
Quinoline	129		
Phenol	94,65		

*Contained in standard mixture.

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SECTION 5
SUMMARY

Exhaust emissions sampling and analysis was performed on Houston Lighting and Power's Unit 52 at the T. H. Wharton Generating Station in Houston, Texas from April 21-24, 1978. Unit 52 is a General Electric Model MS 70001C simple-cycle, single-shaft, heavy-duty gas turbine rated at 70.8 MW nominal electrical output and fired with distillate oil fuel. The unit is equipped with a water injection system for controlling NO_x emissions. The purpose of the tests was to determine the effectiveness of water injection in reducing NO_x and to assess the effects that water injection has on emissions other than NO_x. In addition, operating parameters were recorded so that effects on turbine operation due to water injection could also be observed.

One baseline test (without water injection) and one water injection test, under nominally similar operating conditions, were performed. A summary of the results is presented below.

Unit Operation

The use of water injection did not appear to have any significant impact on unit operations other than an increase in heat rate of approximately 2 percent. This results from some of the fuel heat content being used to vaporize the water. A water/fuel weight ratio of 0.42 was used to reduce NO_x emissions to a level just below the proposed New Source Performance Standard (NSPS) of 75 ppm for stationary gas turbines. A higher or lower water/fuel ratio would respectively raise or lower the resulting heat rate. No other significant operational effects were observed as a result of water injection.

Emissions

Exhaust emissions were measured for changes resulting from the use of water injection for NO_x control. Gaseous, particulate, sulfur species, trace element and organic species emissions were evaluated.

Total NO_x, NO, CO, O_2, CO_2 and total unburned hydrocarbons were measured by continuous monitoring. With water injection operating at a water/fuel weight ratio of 0.42, NO_x emissions were reduced 58 percent from the baseline levels -- from 177.5 to 74.2 ppmv NO_x at 15 percent O_2 dry. SO_2 emissions are wholly determined by the fuel sulfur content and are not affected by water injection. Changes in emissions of CO and total unburned hydrocarbons were within the limits of the analyses. Particulate emissions were very low due to the clean fuel and efficient combustion and did not change significantly with the use of water injection.

It appears that the use of water injection to control NO_x emissions has an insignificant effect on trace element emissions. Furthermore, water injection was found to have little effect on trace element emissions with respect to solid/vapor phase partitioning.

Comparisons of organic species emissions between the baseline and water injection test indicate that water injection has little effect on these emissions. Neither the total organics nor the species and classes of organics changed significantly.

Bioassay tests on the XAD-2 extract from the water injection test showed the exhaust gas to be nonmutagenic and of low toxicity as determined by the Ames Salmonella/microsome plate test and the WI-38 cytotoxicity test respectively.

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APPENDIX A

FUEL ANALYSIS

PART III - Section No. 1

Table No. 1 - Proximate Analysis
Concentration in Wt. %

Parameter	Baseline	Water Injection
Moisture	≤0.01	≤0.01
Volatile Matter	-----	-----
Ash	0.01	≤0.005
Carbon	-----	-----
Sulfur	0.10	0.12
BTU (per lb.)	19849	19751
Specific Gravity at 60°F	0.833	0.831

Table No. 2 - Ultimate Analysis
Concentration in Wt. %

Parameter	Baseline	Water Injection
Moisture	≤0.01	≤0.01
Ash	0.01	0.005
Carbon	81.98	84.91
Hydrogen	13.16	13.25
Nitrogen	0.11	0.17
Chlorine	0.14	0.13
Sulfur	0.10	0.12
Oxygen (by diff.)	4.5	1.42
TOTAL	100.00	100.00

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APPENDIX B

TRACE ELEMENT CONCENTRATIONS -- ppm

Symbols appearing in the tables:

DSCM	Dry Standard Cubic Meter
ESP	Electrostatic Precipitator
kg	Kilogram
MCG	Microgram
min	Minute
ppm	Part per million by weight
<	Less than
*	Sample not analyzed for the particular element/or ionic specie
N	Sample not analyzed
-	Concentration in the sample less than the concentration in the blank

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GAS TURBINE
TRACE ELEMENT CONCENTRATION - (PPM) - FUEL

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .800	< .800
ARSENIC	< 1.00	< 1.00
BARIUM	< .700	< .700
BERYLLIUM	< .300-01	< .300-01
BISMUTH	< .400	< .400
BORON	69.0	53.0
CADMIUM	.900	< .600-01
CHROMIUM	2.90	< .100+00
COBALT	< .200-01	.500-01
COPPER	< .400	< .400
IRON	< .300-01	< .300-01
LEAD	13.0	2.20
MANGANESE	< .100+00	< .100+00
MERCURY	.700	.600
MOLYBDENUM	< 1.00	< 1.00
NICKEL	< .100-01	< .100-01
SELENIUM	3.00	< 2.00
TELLURIUM	< .800	< .800
THALLIUM	< 2.00	< 2.00
TIN	< 3.00	< 3.00
TITANIUM	< 7.00	< 7.00
URANIUM	< 1.00	< 1.00
VANADIUM	< 5.00	< 5.00
ZINC	8.70	7.10
ZIRCONIUM	< 15.0	< 17.0

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (PPM) - WATER

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	N	.000	<	.700-02
ARSENIC	N	.000	<	.200-01
BARIUM	N	.000	<	.400-02
BERYLLIUM	N	.000	<	.200-03
BISMUTH	N	.000	<	.200-02
BORON	N	.000	<	3.00
CADMIUM	N	.000	<	.400-03
CHROMIUM	N	.000	<	.600-03
COBALT	N	.000	<	.100-03
COPPER	N	.000	<	.300-02
IRON	N	.000	<	.300-03
LEAD	N	.000		.190
MANGANESE	N	.000	<	.100-03
MERCURY	N	.000		.880-02
MOLYBDENUM	N	.000		.160
NICKEL	N	.000	<	.100-03
SELENIUM	N	.000	<	.200-01
TELLURIUM	N	.000	<	.600-02
THALLIUM	N	.000	<	.900-02
TIN	N	.000	<	.200-01
TITANIUM	N	.000	<	.600-01
URANIUM	N	.000	*	.000
VANADIUM	N	.000	<	.200-01
ZINC	N	.000		.780-01
ZIRCONIUM	N	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET
DUST SAMPLE

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	10.0	<	10.0
ARSENIC		30.0		40.0
BARIUM	<	7.00		38.0
BERYLLIUM		.600		2.90
BISMUTH	<	2.00	<	2.00
BORON	<	.400+04	<	.300+04
CADMIUM		8.50		7.10
CHROMIUM		260.		210.
COBALT		.500		6.60
COPPER		160.		77.0
IRON		21.0		190.
LEAD		150.		880.
MANGANESE	<	.100+00		.400
MERCURY	<	.900	<	.900
MOLYBDENUM	<	9.00	<	7.00
NICKEL		3.00		35.0
SELENIUM	<	30.0	<	20.0
TELLURIUM	<	10.0	<	8.00
THALLIUM	<	20.0		30.0
TIN	<	300.		.280+04
TITANIUM	<	60.0	<	50.0
URANIUM	*	.000	*	.000
VANADIUM		57.0		45.0
ZINC		.540+05		.630+05
ZIRCONIUM	*	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .700	< .800
ARSENIC	< 2.00	< 2.00
BARIUM	< .600	< .600
BERYLLIUM	< .200-01	< .200-01
BISMUTH	< .300	< .400
BORON	< 370.	< 360.
CADMIUM	< .400-01	< .400-01
CHROMIUM	< .500-01	< .600-01
COBALT	< .800-02	< .800-02
COPPER	2.80	6.60
IRON	11.0	15.0
LEAD	15.0	2.40
MANGANESE	< .800-02	< .800-02
MERCURY	.440	4.30
MOLYBDENUM	< .900	< .900
NICKEL	< .800-02	< .800-02
SELENIUM	< 2.00	< 2.00
TELLURIUM	< .600	< .600
THALLIUM	< 2.00	< 2.00
TIN	< 2.00	< 2.00
TITANIUM	< 5.00	< 6.00
URANIUM	* .000	* .000
VANADIUM	4.00	10.0
ZINC	< .600	4.00
ZIRCONIUM	* .000	* .000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET
FIRST IMPINGER

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	.600-02	<	.500-02
ARSENIC	<	.300-01	<	.300-01
BARIUM		.500-02	<	.400-02
BERYLLIUM	<	.200-03	<	.200-03
BISMUTH	<	.400-02	<	.500-02
BORON	<	3.00	<	3.00
CADMIUM		.200		.370-02
CHROMIUM		.200		.630-01
COBALT	<	.100-03	<	.200-03
COPPER		.390		.370
IRON		.210		.210
LEAD		.300-01		.160-01
MANGANESE	<	.700-04	<	.100-03
MERCURY	<	.700-03	<	.100-02
MOLYBDENUM		.150-01	<	.600-02
NICKEL		.240-02		.210-02
SELENIUM	<	.100-01	<	.100-01
TELLURIUM	<	.600-02	<	.600-02
THALLIUM	<	.500-02	<	.600-02
TIN	<	.200-01	<	.200-01
TITANIUM	<	.400-01	<	.500-01
URANIUM	*	.000	*	.000
VANADIUM	<	.700-02	<	.100-01
ZINC		.560		.530
ZIRCONIUM	*	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (PPM) - UNIT OUTLET
2ND & 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	.500-02	<	.600-02
ARSENIC	<	.200-01	<	.300-01
BARIUM	*	.000	*	.000
BERYLLIUM	*	.000	*	.000
BISMUTH	*	.000	*	.000
BORON	*	.000	*	.000
CADMIUM	*	.000	*	.000
CHROMIUM	*	.000	*	.000
COBALT	*	.000	*	.000
COPPER	*	.000	*	.000
IRON	*	.000	*	.000
LEAD	*	.000	*	.000
MANGANESE	*	.000	*	.000
MERCURY		.500-02	<	.300-02
MOLYBDENUM	*	.000	*	.000
NICKEL	*	.000	*	.000
SELENIUM	*	.000	*	.000
TELLURIUM	*	.000	*	.000
THALLIUM	*	.000	*	.000
TIN	*	.000	*	.000
TITANIUM	*	.000	*	.000
URANIUM	*	.000	*	.000
VANADIUM	*	.000	*	.000
ZINC	*	.000	*	.000
ZIRCONIUM	*	.000	*	.000

APPENDIX C

TRACE ELEMENT FLOWRATES -- kg/min

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (KG/MIN) - FUEL

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .235-03	< .236-03
ARSENIC	< .294-03	< .296-03
BARIUM	< .206-03	< .207-03
BERYLLIUM	< .883-05	< .887-05
BISMUTH	< .118-03	< .118-03
BORON	.203-01	.157-01
CADMIUM	.265-03	< .177-04
CHROMIUM	.853-03	< .296-04
COBALT	< .588-05	.148-04
COPPER	< .118-03	< .118-03
IRON	< .883-05	< .887-05
LEAD	.382-02	.650-03
MANGANESE	< .294-04	< .296-04
MERCURY	.206-03	.177-03
MOLYBDENUM	< .294-03	< .296-03
NICKEL	< .294-05	< .296-05
SELENIUM	.883-03	< .591-03
TELLURIUM	< .235-03	< .236-03
THALLIUM	< .588-03	< .591-03
TIN	< .883-03	< .887-03
TITANIUM	< .206-02	< .207-02
URANIUM	< .294-03	< .296-03
VANADIUM	< .147-02	< .148-02
ZINC	.256-02	.210-02
ZIRCONIUM	< .441-02	< .502-02

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GAS TURBINE
TRACE ELEMENT CONCENTRATION - (KG/MIN) - WATER

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	N	.000	<	.103-05
ARSENIC	N	.000	<	.295-05
BARIUM	N	.000	<	.591-06
BERYLLIUM	N	.000	<	.295-07
BISMUTH	N	.000	<	.295-06
BORON	N	.000	<	.443-03
CADMIUM	N	.000	<	.591-07
CHROMIUM	N	.000	<	.886-07
COBALT	N	.000	<	.148-07
COPPER	N	.000	<	.443-06
IRON	N	.000	<	.443-07
LEAD	N	.000		.281-04 ⊦
MANGANESE	N	.000	<	.148-07
MERCURY	N	.000		.130-05
MOLYBDENUM	N	.000		.236-04 ⊦
NICKEL	N	.000	<	.148-07
SELENIUM	N	.000	<	.295-05
TELLURIUM	N	.000	<	.886-06
THALLIUM	N	.000	<	.133-05
TIN	N	.000	<	.295-05
TITANIUM	N	.000	<	.886-05
URANIUM	N	.000	*	.000
VANADIUM	N	.000	<	.295-05
ZINC	N	.000		.115-04
ZIRCONIUM	N	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (KG/MIN) - UNIT OUTLET
DUST SAMPLE

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	.165-05	<	.143-05
ARSENIC		.494-05		.571-05
BARIUM	<	.115-05		.542-05
BERYLLIUM		.989-07		.414-06
BISMUTH	<	.330-06	<	.285-06
BORON	<	.659-03	<	.428-03
CADMIUM		.140-05		.101-05
CHROMIUM		.429-04		.300-04
COBALT		.824-07		.942-06
COPPER		.264-04		.110-04
IRON		.346-05		.271-04
LEAD		.247-04		.126-03
MANGANESE	<	.165-07		.571-07
MERCURY	<	.148-06	<	.128-06
MOLYBDENUM	<	.148-05	<	.999-06
NICKEL		.494-06		.500-05
SELENIUM	<	.494-05	<	.285-05
TELLURIUM	<	.165-05	<	.114-05
THALLIUM	<	.330-05		.428-05
TIN	<	.494-04		.400-03
TITANIUM	<	.989-05	<	.714-05
URANIUM	*	.000	*	.000
VANADIUM		.939-05		.642-05
ZINC		.890-02		.899-02
ZIRCONIUM	*	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (KG/MIN) - UNIT OUTLET
XAU-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .450-04	< .459-04
ARSENIC	< .129-03	< .115-03
BARIUM	< .386-04	< .344-04
BERYLLIUM	< .129-05	< .115-05
BISMUTH	< .193-04	< .229-04
BORON	< .238-01	< .206-01
CADMIUM	< .257-05	< .229-05
CHROMIUM	< .322-05	< .344-05
COBALT	< .515-06	< .459-06
COPPER	.180-03	.378-03
IRON	.708-03	.860-03
LEAD	.965-03	.138-03
MANGANESE	< .515-06	< .459-06
MERCURY	.283-04	.246-03
MOLYBDENUM	< .579-04	< .516-04
NICKEL	< .515-06	< .459-06
SELENIUM	< .129-03	< .115-03
TELLURIUM	< .386-04	< .344-04
THALLIUM	< .129-03	< .115-03
TIN	< .129-03	< .115-03
TITANIUM	< .322-03	< .344-03
URANIUM	* .000	* .000
VANADIUM	.257-03	.573-03
ZINC	< .386-04	.229-03
ZIRCONIUM	* .000	* .000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (KG/MIN) - UNIT OUTLET
FIRST IMPINGER

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .478-05	< .456-05
ARSENIC	< .239-04	< .274-04
BARIUM	.398-05	< .365-05
BERYLLIUM	< .159-06	< .182-06
BISMUTH	< .319-05	< .456-05
BORON	< .239-02	< .274-02
CADMIUM	.159-03	.337-05
CHROMIUM	.159-03	.575-04
COBALT	< .797-07	< .182-06
COPPER	.311-03	.337-03
IRON	.167-03	.192-03
LEAD	.239-04	.146-04
MANGANESE	< .558-07	< .912-07
MERCURY	< .558-06	< .912-06
MOLYBDENUM	.120-04	< .547-05
NICKEL	.191-05	.192-05
SELENIUM	< .797-05	< .912-05
TELLURIUM	< .478-05	< .547-05
THALLIUM	< .398-05	< .547-05
TIN	< .159-04	< .182-04
TITANIUM	< .319-04	< .456-04
URANIUM	* .000	* .000
VANADIUM	< .558-05	< .912-05
ZINC	.446-03	.483-03
ZIRCONIUM	* .000	* .000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (KG/MIN) - UNIT OUTLET
2ND & 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .537-05	< .494-05
ARSENIC	< .215-04	< .247-04
BARIUM	* .000	* .000
BERYLLIUM	* .000	* .000
BISMUTH	* .000	* .000
BORON	* .000	* .000
CADMIUM	* .000	* .000
CHROMIUM	* .000	* .000
COBALT	* .000	* .000
COPPER	* .000	* .000
IRON	* .000	* .000
LEAD	* .000	* .000
MANGANESE	* .000	* .000
MERCURY	.537-05	< .247-05
MOLYBDENUM	* .000	* .000
NICKEL	* .000	* .000
SELENIUM	* .000	* .000
TELLURIUM	* .000	* .000
THALLIUM	* .000	* .000
TIN	* .000	* .000
TITANIUM	* .000	* .000
URANIUM	* .000	* .000
VANADIUM	* .000	* .000
ZINC	* .000	* .000
ZIRCONIUM	* .000	* .000

APPENDIX D

TRACE ELEMENT FLOWRATES -- MCG/Joule

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/JOULE) - FUEL

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .174-04	< .175-04
ARSENIC	< .218-04	< .219-04
BARIUM	< .152-04	< .153-04
BERYLLIUM	< .653-06	< .656-06
BISMUTH	< .871-05	< .875-05
BORON	.150-02	.116-02
CADMIUM	.196-04	< .131-05
CHROMIUM	.631-04	< .219-05
COBALT	< .435-06	.109-05
COPPER	< .871-05	< .875-05
IRON	< .653-06	< .656-06
LEAD	.283-03	.481-04
MANGANESE	< .218-05	< .219-05
MERCURY	.152-04	.131-04
MOLYBDENUM	< .218-04	< .219-04
NICKEL	< .218-06	< .219-06
SELENIUM	.653-04	< .437-04
TELLURIUM	< .174-04	< .175-04
THALLIUM	< .435-04	< .437-04
TIN	< .653-04	< .656-04
TITANIUM	< .152-03	< .153-03
URANIUM	< .218-04	< .219-04
VANADIUM	< .109-03	< .109-03
ZINC	.189-03	.155-03
ZIRCONIUM	< .327-03	< .372-03

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GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/JOULE) - WATER

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	N	.000	<	.765-07
ARSENIC	N	.000	<	.219-06
BARIUM	N	.000	<	.437-07
BERYLLIUM	N	.000	<	.219-08
BISMUTH	N	.000	<	.219-07
BORON	N	.000	<	.328-04
CADMIUM	N	.000	<	.437-08
CHROMIUM	N	.000	<	.656-08
COBALT	N	.000	<	.109-08
COPPER	N	.000	<	.328-07
IRON	N	.000	<	.328-08
LEAD	N	.000		.208-05
MANGANESE	N	.000	<	.109-08
MERCURY	N	.000		.962-07
MOLYBDENUM	N	.000		.175-05
NICKEL	N	.000	<	.109-08
SELENIUM	N	.000	<	.219-06
TELLURIUM	N	.000	<	.656-07
THALLIUM	N	.000	<	.984-07
TIN	N	.000	<	.219-06
TITANIUM	N	.000	<	.656-06
URANIUM	N	.000	*	.000
VANADIUM	N	.000	<	.219-06
ZINC	N	.000		.853-06
ZIRCONIUM	N	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/JOULE) - UNIT OUTLET
DUST SAMPLE

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	.122-06	<	.106-06
ARSENIC		.366-06		.423-06
BARIUM	<	.855-07		.402-06
BERYLLIUM		.732-08		.307-07
BISMUTH	<	.244-07	<	.211-07
BORON	<	.488-04	<	.317-04
CADMIUM		.104-06		.751-07
CHROMIUM		.317-05		.222-05
COBALT		.610-08		.698-07
COPPER		.195-05		.814-06
IRON		.256-06		.201-05
LEAD		.183-05		.930-05
MANGANESE	<	.122-08		.423-08
MERCURY	<	.110-07	<	.951-08
MOLYBDENUM	<	.110-06	<	.740-07
NICKEL		.366-07		.370-06
SELENIUM	<	.366-06	<	.211-06
TELLURIUM	<	.122-06	<	.846-07
THALLIUM	<	.244-06		.317-06
TIN	<	.366-05		.296-04
TITANIUM	<	.732-06	<	.529-06
URANIUM	*	.000	*	.000
VANADIUM		.696-06		.476-06
ZINC		.659-03		.666-03
ZIRCONIUM	*	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/JOULE) - UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .334-05	< .340-05
ARSENIC	< .953-05	< .849-05
BARIUM	< .286-05	< .255-05
BERYLLIUM	< .953-07	< .849-07
BISMUTH	< .143-05	< .170-05
BORON	< .176-02	< .153-02
CADMIUM	< .191-06	< .170-06
CHROMIUM	< .238-06	< .255-06
COBALT	< .381-07	< .340-07
COPPER	.133-04	.280-04
IRON	.524-04	.637-04
LEAD	.715-04	.102-04
MANGANESE	< .381-07	< .340-07
MERCURY	.210-05	.183-04
MOLYBDENUM	< .429-05	< .382-05
NICKEL	< .381-07	< .340-07
SELENIUM	< .953-05	< .849-05
TELLURIUM	< .286-05	< .255-05
THALLIUM	< .953-05	< .849-05
TIN	< .953-05	< .849-05
TITANIUM	< .238-04	< .255-04
URANIUM	* .000	* .000
VANADIUM	.191-04	.425-04
ZINC	< .286-05	.170-04
ZIRCONIUM	* .000	* .000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/JOULE) - UNIT OUTLET
FIRST IMPINGER

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .354-06	< .338-06
ARSENIC	< .177-05	< .203-05
BARIUM	.295-06	< .270-06
BERYLLIUM	< .118-07	< .135-07
BISMUTH	< .236-06	< .338-06
BORON	< .177-03	< .203-03
CADMIUM	.118-04	.250-06
CHROMIUM	.118-04	.426-05
COBALT	< .590-08	< .135-07
COPPER	.230-04	.250-04
IRON	.124-04	.142-04
LEAD	.177-05	.108-05
MANGANESE	< .413-08	< .675-08
MERCURY	< .413-07	< .675-07
MOLYBDENUM	.885-06	< .405-06
NICKEL	.142-06	.142-06
SELENIUM	< .590-06	< .675-06
TELLURIUM	< .354-06	< .405-06
THALLIUM	< .295-06	< .405-06
TIN	< .118-05	< .135-05
TITANIUM	< .236-05	< .338-05
URANIUM	* .000	* .000
VANADIUM	< .413-06	< .675-06
ZINC	.330-04	.358-04
ZIRCONIUM	* .000	* .000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/JOULE) - UNIT OUTLET
2ND & 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .398-06	< .366-06
ARSENIC	< .159-05	< .183-05
BARIUM	* .000	* .000
BERYLLIUM	* .000	* .000
BISMUTH	* .000	* .000
BORON	* .000	* .000
CADMIUM	* .000	* .000
CHROMIUM	* .000	* .000
COBALT	* .000	* .000
COPPER	* .000	* .000
IRON	* .000	* .000
LEAD	* .000	* .000
MANGANESE	* .000	* .000
MERCURY	.398-06	< .183-06
MOLYBDENUM	* .000	* .000
NICKEL	* .000	* .000
SELENIUM	* .000	* .000
TELLURIUM	* .000	* .000
THALLIUM	* .000	* .000
TIN	* .000	* .000
TITANIUM	* .000	* .000
URANIUM	* .000	* .000
VANADIUM	* .000	* .000
ZINC	* .000	* .000
ZIRCONIUM	* .000	* .000

APPENDIX E

TRACE ELEMENT CONCENTRATION -- MCG/DSCM

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/DSCM) - UNIT OUTLET
DUST SAMPLE

TRACE ELEMENT	TEST CONDITION	
CATIONS	BASELINE, NO WATER	WATER INJECTION
ANTIMONY	< .133	< .118
ARSENIC	.400	.473
BARIUM	< .934-01	.449
BERYLLIUM	.800-02	.343-01
BISMUTH	< .267-01	< .236-01
BORON	< 53.4	< 35.4
CADMIUM	.113	.839-01
CHROMIUM	3.47	2.48
COBALT	.667-02	.780-01
COPPER	2.13	.910
IRON	.280	2.25
LEAD	2.00	10.4
MANGANESE	< .133-02	.473-02
MERCURY	< .120-01	< .106-01
MOLYBDENUM	< .120	< .827-01
NICKEL	.400-01	.414
SELENIUM	< .400	< .236
TELLURIUM	< .133	< .945-01
THALLIUM	< .267	.354
TIN	< 4.00	33.1
TITANIUM	< .800	< .591
URANIUM	* .000	* .000
VANADIUM	.760	.532
ZINC	720.	744.
ZIRCONIUM	* .000	* .000

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GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/DSCM) - UNIT OUTLET
XAD-2 CARTRIDGE

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	3.64	<	3.80
ARSENIC	<	10.4	<	9.49
BARIUM	<	3.12	<	2.85
BERYLLIUM	<	.104	<	.949-01
BISMUTH	<	1.56	<	1.90
BORON	<	.193+04	<	.171+04
CADMIUM	<	.208	<	.190
CHROMIUM	<	.260	<	.285
COBALT	<	.417-01	<	.380-01
COPPER		14.6		31.3
IRON		57.3		71.2
LEAD		78.1		11.4
MANGANESE	<	.417-01	<	.380-01
MERCURY		2.29		20.4
MOLYBDENUM	<	4.69	<	4.27
NICKEL	<	.417-01	<	.380-01
SELENIUM	<	10.4	<	9.49
TELLURIUM	<	3.12	<	2.85
THALLIUM	<	10.4	<	9.49
TIN	<	10.4	<	9.49
TITANIUM	<	26.0	<	28.5
URANIUM	*	.000	*	.000
VANADIUM		20.8		47.5
ZINC	<	3.12		19.0
ZIRCONIUM	*	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/DSCM) - UNIT OUTLET
FIRST IMPINGER

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	.387	<	.378
ARSENIC	<	1.93	<	2.27
BARIUM		.322	<	.302
BERYLLIUM	<	.129-01	<	.151-01
BISMUTH	<	.258	<	.378
BORON	<	193.	<	227.
CADMIUM		12.9		.279
CHROMIUM		12.9		4.76
COBALT	<	.645-02	<	.151-01
COPPER		25.1		27.9
IRON		13.5		15.9
LEAD		1.93		1.21
MANGANESE	<	.451-02	<	.755-02
MERCURY	<	.451-01	<	.755-01
MOLYBDENUM		.967	<	.453
NICKEL		.155		.159
SELENIUM	<	.645	<	.755
TELLURIUM	<	.387	<	.453
THALLIUM	<	.322	<	.453
TIN	<	1.29	<	1.51
TITANIUM	<	2.58	<	3.78
URANIUM	*	.000	*	.000
VANADIUM	<	.451	<	.755
ZINC		36.1		40.0
ZIRCONIUM	*	.000	*	.000

GAS TURBINE
TRACE ELEMENT CONCENTRATION - (MCG/DSCM) - UNIT OUTLET
2ND & 3RD IMPINGER

TRACE ELEMENT	TEST CONDITION			
CATIONS	BASELINE, NO WATER		WATER INJECTION	
ANTIMONY	<	.435	<	.409
ARSENIC	<	1.74	<	2.05
BARIUM	*	.000	*	.000
BERYLLIUM	*	.000	*	.000
BISMUTH	*	.000	*	.000
BORON	*	.000	*	.000
CADMIUM	*	.000	*	.000
CHROMIUM	*	.000	*	.000
COBALT	*	.000	*	.000
COPPER	*	.000	*	.000
IRON	*	.000	*	.000
LEAD	*	.000	*	.000
MANGANESE	*	.000	*	.000
MERCURY		.435	<	.205
MOLYBDENUM	*	.000	*	.000
NICKEL	*	.000	*	.000
SELENIUM	*	.000	*	.000
TELLURIUM	*	.000	*	.000
THALLIUM	*	.000	*	.000
TIN	*	.000	*	.000
TITANIUM	*	.000	*	.000
URANIUM	*	.000	*	.000
VANADIUM	*	.000	*	.000
ZINC	*	.000	*	.000
ZIRCONIUM	*	.000	*	.000

APPENDIX F

ORGANIC ANALYSIS RESULTS

TABLE F-1. IR ANALYSIS REPORT

Contractor Acurex

Sample Site Houston Lighting + Power **Sample Acquisition Date** 4-22-78

Type of Source Organic extracts from XAD-2 resin, SASS Train.

Test Number **Sample ID Number** HLP-1-X

Sample Description Baseline

Responsible Analyst Henriette Atkins **Date Analyzed** 8-21-78

Calculations and Report Reviewed By M Beth Heffernin **Report Date** 9-26-78

Instrument Perkin-Elmer M. 297 **Sample Cell Type** smear on NaCl plate

Utilized Max/Min Signal Intensity Values

Observations Obviously, carboxylic acid and/or ester and alcohol are major component

Wave Number (cm^{-1})	Intensity	Assignment	Comments
3400-3500	s	O-H	broad peak
2960, 2920,			
- 2850	s	C-H	aliphatic
1720-1700	s	C=O	carbonyl possibly ester
1600	w	C=C	unsaturated, aromatic
1450	m	$-CH_3$ bending	methyl groups
1370	m		possibly methyl
1260	s	-O- bending	ether/ester
1070-1090	m	unassigned	broad peak
800	w	unassigned }	possibly aromatic
710	w	unassigned }	substitution bands

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TABLE F-2. IR ANALYSIS REPORT

Contractor Acurex

Sample Site Houston L+P unit #52 **Sample Acquisition Date** 4-24-78

Type of Source XAD-2 resin, SASS train turbine outlet

Test Number ______ **Sample ID Number** HLP-2-X

Sample Description condensed organic extracts from XAD-2 resin water addition.

Responsible Analyst Harriette Atkins **Date Analyzed** 8-21-78

Calculations and Report Reviewed By M. Beth Heffernan **Report Date** ______

Instrument Perkin-Elmer M. 297 **Sample Cell Type** Smear on NaCl plate

Utilized Max/Min Signal Intensity Values ______

Observations obviously carboxylic acid and ester (or ½ ester) principal constituent.

Wave Number (cm⁻¹)	Intensity	Assignment	Comments
3400-3500	s	O-H	broad peak
2960 2920			
- 2850	s	C-H	aliphatic
1690-1720	s	C=O	carbonyl, broad
1600	w	C=C	unsaturation, aromatic
1450, 1460	m	$-CH_3$	, methyl band
1380	m		possibly methyl
1260	s	-O-	ether / ester
1070-1100	s	unassigned	broad peak
800	m	unassigned }	aromatic substitution
710,700sh	m	unassigned)	bands

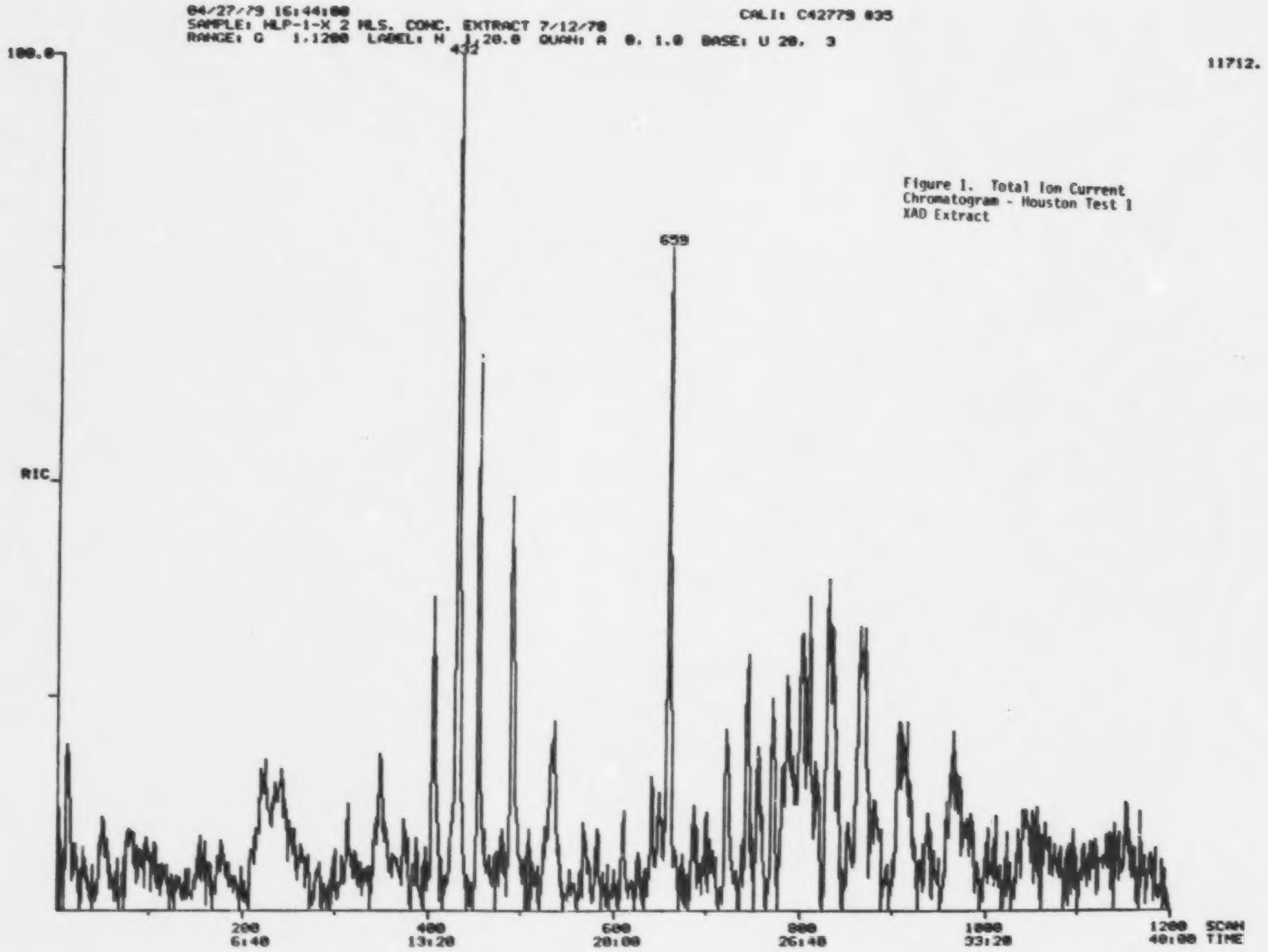

Figure F-1. Total ion current chromatogram -- Houston test 1 XAD extract.

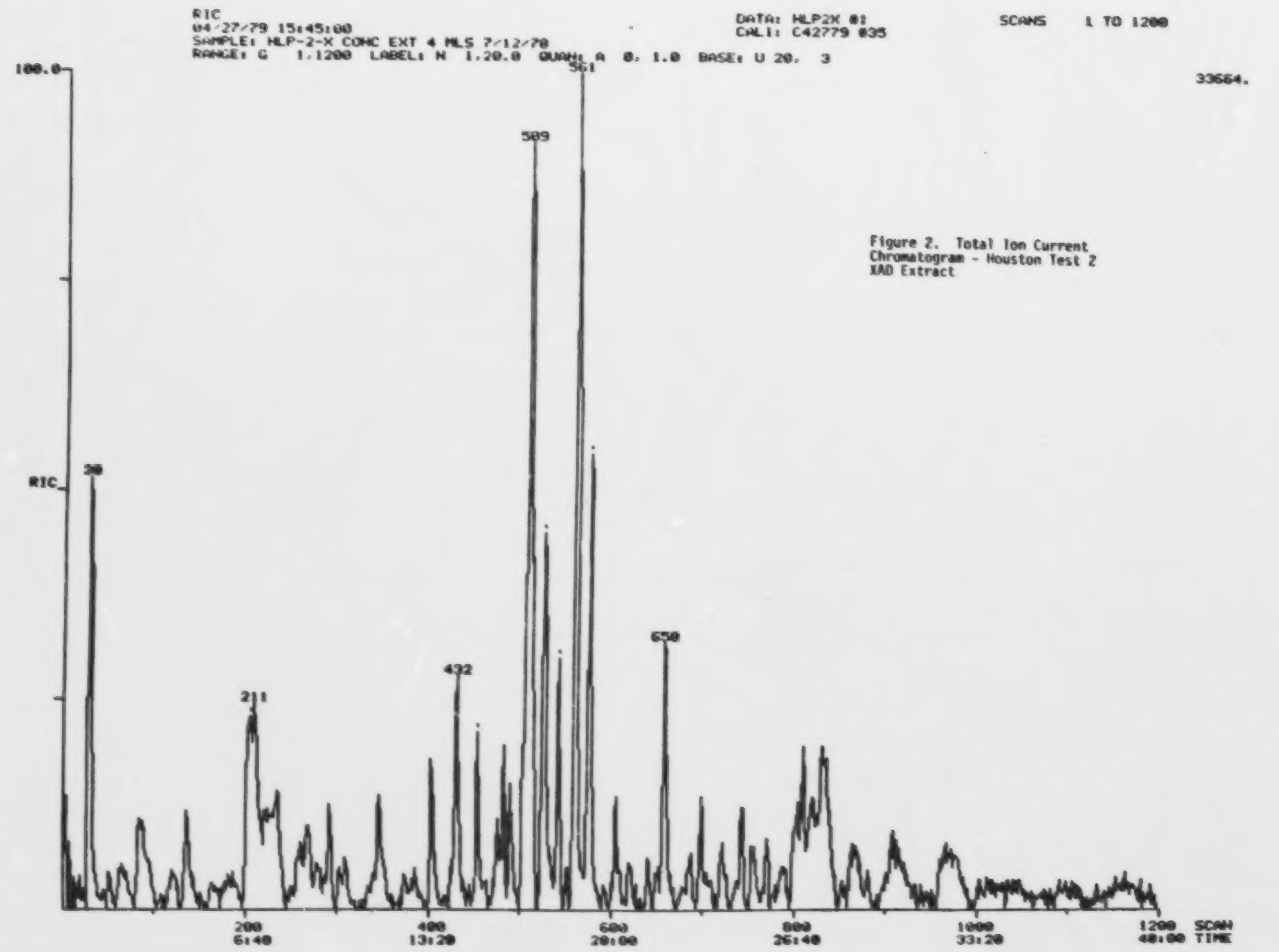

Figure F-2. Total ion current chromatogram -- Houston test 2 XAD extract.

APPENDIX G

GENERAL ELECTRIC TEST RESULTS

GENERAL ELECTRIC

GAS TURBINE
PRODUCTS DIVISION

GENERAL ELECTRIC COMPANY, ONE RIVER ROAD, SCHENECTADY, N.Y., U.S.A. 12345
Phone (518) 374-2211, Telex 145354

July 13, 1978

Mr. Brent Higginbotham
Acurex Aerotherm
485 Clyde Avenue
Mountain View, CA. 94042

Dear Brent:

Five copies of General Electric's report on the Acurex-GE joint test at Houston Lighting and Power are attached. These should provide sufficient data for your analysis, but don't hesitate to contact us if you have further questions.

Working with the Acurex test team was a pleasant experience. Perhaps there will be other opportunities for such tests.

Sincerely yours,

L. Berkley Davis

L. Berkley Davis, Engineer
Combustion Development-LGT
Bldg. 53 - Rm. 322

Attachments

LBD:rhb

cc: Nancy Fitzroy, 500-224
M. B. Hilt, 53-322

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MS7001C FIELD TEST RESULTS
UNIT 52, HOUSTON LIGHTING AND POWER
APRIL 1978

During the recent field test of a MS7001C gas turbine, Unit 52, at Houston Lighting and Power, personnel from General Electric's Gas Turbine Division were responsible for measuring gaseous emissions and assessing turbine operation.

This report details the results of these tests and fulfills General Electric's reporting requirements to Acurex under contract RB68439A.

1. RESULTS

Some nineteen test points were run over a period from April 21 to 24, 1978. As indicated, these were spread over three days, with the first day devoted to a preliminary test to establish the velocity profile in the exhaust duct.

DATE	TEST
APRIL 21	PRELIMINARY TEST, VELOCITY TRAVERSE
APRIL 22	BASE LOAD, NO WATER INJECTION
APRIL 24	BASE LOAD, WATER INJECTION

At each test point, gaseous emissions (O_2, CO_2, NO_x, NO, unburned hydrocarbons (UHC), and CO were measured at a single point in the exhaust duct.

Machine operating data, sufficient to establish the airflow rate and operating state of the machine, were also recorded.

The subsequent discussion in part III of this report will address the quality of results expected from single point sampling, as compared to those from a traverse.

Tables (1-2) list the data points for each of the three days. Data from a point are input to a data analysis program called FIRCAL9.

This program utilizes machine performance data, gaseous emissions, fuel composition, and machine geometry and internal flow splits to predict machine operational characteristics. For example, compressor inlet airflow is calculated using four methods; refer to Table (3) for an output sheet from FIRCAL9.

Each column of results (e.g., FT. TEST FLOW) makes use of certain of the data to calculate machine airflow, turbine inlet temperature and exhaust composition. This is illustrated in the table given below.

COLUMN	MEASURED	CALCULATED
FT. TEST FLOW	fuel flow and composition, airflow during factory test, inlet guide lane position, ambient conditions	machine airflow, O_2 CO_2, water in exhaust, turbine inlet temperature.
CHKD. FLOW	compressor discharge pressure and temperature, first stage nozzle area, fuel flow and composition.	machine airflow/turbine inlet temp., O_2, CO_2, H_2O
OXYGEN CONC.	O_2, fuel flow and composition	machine airflow, CO_2, H_2O, turbine inlet temperature
CO_2 CONC.	CO_2, fuel flow and composition	machine airflow, turbine inlet temperature, O_2, H_2O

Turbine temperatures are proprietary to General Electric and are not included in the results.

Results tables for each test point are interpreted as described in Table (3). The complete sets of results are given in Tables (3-17).

II. DISCUSSION

The core of the test results is contained in the test points 6-11 and 14-18. The first set is at base load with no water injection, while the second is at base load with 40 gpm water injection. The main points to note are the NO_x, NO_x(ISO), O_2, and airflow rates.

Emissions of nitrogen oxides from a gas turbine are strongly affected by ambient humidity. This is taken into account using the relationship*

$$NO_x(ISO) = NO_x(MEASURED)\, e^{23.2(H-.0063)}$$

While measured NO_x varied considerably during the course of the dry test (pts.6-11) in response to a cold front moving through, NO_x(ISO) changes about ± 1 percent. A similar statement applies to results from the water injection test (pts. 14-18).

---

* The constant 23.2 appearing in the exponential is derived from General Electric data. It gives numbers 2.7 percent higher than the EPA constant of 19.0.

NO_x EMISSIONS

OPERATING POINT	MEAN NO_x(ISO) ppmv	MEAN O_2 (% by Vol.,dry)
BASE, DRY	159.1 ± 1.0%	15.30 $^{+1.7\%}_{-3.5\%}$
BASE, 40 gpm	67.7 ± 1.1%	15.12 ±1%

The variation* in O_2 measurements during the dry test is somewhat larger than that in NO_x(ISO). This is apparently an outright measurement error in one point (pt. 8) that was taken during the period of severe weather.

Airflow in a gas turbine is directly affected by ambient variations and as the numbers in the tables vary by some ± 2.5 percent with time. The mean levels (for, say, FT. TEST FLOW) are representative of the expected performance of the MS7001C axial compressor.

A comparison of the compressor inlet airflow values from each of the four calculation schemes (CHKD. FLOW, etc.) reveals excellent agreement (± 1.0%) between airflow from FT. TEST FLOW, CHKD. FLOW, and OXYGEN CONC. Note that pt. 8 is an exception (± 2.2%).

The airflow calculated from measured CO_2 (CO_2 CONC.) shows relatively poor consistancy and agreement with the other values. This is particularly apparent in the water injection test, where the airflows predicted from measured CO_2 concentration are approximately ten percent higher than expected.

---

*This variation is calculated as a deficit from 21 percent atmospheric O_2.

The large amounts of water vapor in the exhaust obviously affect the instrument.

The SO_2 values in the tables are calculated assuming one hundred percent conversion of fuel sulfur. This is consistent with General Electric's experience.

Two fuel analyses are given in Table (18). The variation in measured hydrogen is typical of that found from repeated measurements of distillate fuels. The ash content is, in both cases, higher than expected for distillates.

Table (19) gives a breakdown of the ash, with the primary constituent being an oxide of zinc. The hydrogen values in Table (19) are determined using the Galbraith method and are not as accurate as those in Table (18).

III. SUPPORTING TESTS

Subsequent to the Acurex tests, considerable effort was put into obtaining very accurate hydrocarbon measurements. In preparation for these tests, the stainless sampling probe was washed with acetone and methylene chloride, passivated with nitric acid, and washed again with methylene chloride.

In addition, an abbreviated stack traverse (18 pts.) was made.

There are two aspects of this portion of the testing of interest to Acurex: the hydrocarbon readings themselves, and the variation of No_x and O_2 over the cross section of the exit duct.

Figures (1-3) give the results taken from a base load point with 40 gpm of water being injected. Each figure shows a definite profile across the stack, with a 3 NOx variation of ± 5.9% (± 3.3 ppmv). The point customarily used for single point sampling is just above position D-4. These data indicate that the NOx is approximately 2.2% lower than the mean value at that point. Thus, the readings reported in the previous section would be within two percent of the true mean.

Oxygen readings have a $\pm 3\sigma$ variation of ± 4.5% (referenced to $21 - \overline{O}_2$), and verify the trends observed in NOx. Unburned hydrocarbons are quite low ($<$ 2 ppmv); they show a very wide spread (3σ is ± 79 percent).

Other points presented in the tables give supporting data. For example, points 12 and 19 are at base load, dry; they were taken just before and just after the water injection test. Note that NOx(ISO) values are in excellent agreement with those previously obtained.

Machine performance and emissions measurements taken from Unit 52 at Houston Lighting and Power are both self-consistent and in agreement with data acquired from other machines of this class.

Close agreement between airflows from different methods of calculation give considerable confidence in the airflow levels. Any discrepancy between these values and that obtained during a stack traverse should be carefully reviewed.

Single point sampling should give adequate results for gaseous emissions such as NOx and O_2. Measurement of species present at very low concentrations requires a traverse.

TABLE 1

(12)

To
Acurex

GENERAL ELECTRIC CO. SCHENECTADY, N.Y.

GAS TURBINE TEST DATA

POINT ____

SHEET ____

DATE 4-21-78 / 4-22-78

BAR. ____ 0 ____ F°

BAR. TIME ____

OBSERVER ____

APPARATUS HOUSTON UNIT 52

TEST ____

CONDITIONS ____

DATA ____

	DATE	4-21-78	4-21-78	4-21-78	4-21-78	4-22-78	4-22-78	4-22-78	4-22-78	4-22-78	4-22-78	4-22-78			
	TIME	17:35	18:45	19:20	19:45	15:17	17:08	18:00	20:00	21:00	22:00	23:00			
	POINT	1	2	3	4	5	6	7	8	9	10	11			
	PCD	130.5		132.4		119.2	131.0	131.9	134.2	132.0	132.2	131.9			
	TCD	613.0		605	602	590	612	609	605	607	608	609			
	SPEED	3600		3600	3600	3600	3600	3600	3600	3600	3600	3600			
	VCE	7.4													
	IGV	77°	77°	77°	77°	77°	77°	77°	77°	77°	77°	77°			
	LOAD	59.3	59.0	60.0	60.0	40.0	61.0	62.0	61.8	62.0	63.0	62.0			
Exhaust Temp	1-2														
	3-4														
	5-6														
	7-8														
	9-10														
	11-12														
	AVG	978	975	971	969		1002	999	995	996	999	999			
H_2O Inj.	GPM	0		0		0	0	0	0	0	0	0			
	TEMP	0		0						0					
Noz Press.	1-2														
	3-4														
	5-6														
	7-8														
	9-10														
Fuel Oil	TEMP	72°F		66°F			73°F	72°F	73°F	70°F	72°F	72°F			
	TIME	1 min		1 min			1:04.5	1:04.1	2:06.5	2:08.5	2:07.5	2:07.9			
	GAL	91 gpm		92 gpm			100	100	200	200	200	200			
	PAAM	.196		199		180	198	198	200	200	199	198			
	TAAM	390		390		390	395	390	395	390	392	390			
Fuel Gas	P_1														
	P_2														
	P_3														
	POSIT.														
	TEMP.														

TABLE 2

To
Acurex

(12)

GENERAL ELECTRIC CO. SCHENECTADY, N.Y.

GAS TURBINE TEST DATA

APPARATUS Houston Unit 52
TEST
CONDITIONS
DATA

POINT
SHEET
DATE 4-24-78
BAR. ______ @ ______ °F
BAR. TIME
OBSERVER MAZZONE - RUSKIN

	DATE TIME POINT	4-24-78 13:10 12	4-24-78 14:10 13	4-24-78 15:00 14	4-24-78 16:00 15	4-24-78 17:00 16	4-24-78 18:00 17	4-24-78 19:00 18	4-24-78 19						
	PCD	129.5	130.2	130.5	130.1	129.9	130.8	132.2	131.8						
	TCD	619	624	627	626	628	624	616	612						
	Speed	3600	3600	3600	3600	3600	3600	3600	3600						
	VCE														
	[illegible]	77°	77°	77°	77°	77°	77°	77°	77°						
	Load	60.0	60.0	61.0	61.0	61.0	61.5	63.0	62.0						
Exhaust Temp	1-2														
	3-4														
	5-6														
	7-8														
	9-10														
	11-12														
	AVG	1001	1001	1001	1001	1001	1001	996	999						
H_2O Inj.	GPM	0	20	40	40	40	40	40	0						
	Temp														
Noz Press.	1-2														
	3-4														
	5-6														
	7-8														
	9-10														
Fuel Oil	Temp	80°	80°	81°	80°	77°	74°	70°	70°						
	Time	2:11.2	2:08.5	2:06.3	2:06.0	2:06.6	2:05.5	2:03.6	2:08.3						
	Gal	200	200	200	200	200	200	200	200						
	PARM	195	198	199	198	198	199	200	198						
	TARM	395	—	385	385	390	385	390	395						
Fuel Gas	P_1														
	P_2														
	P_3														
	Posit.														
	Temp														

TABLE 3

```
                 04/22/78   12.52HOURS
                 FIRCAL9 REVISED 03/30/78
               HOUSTON LIGHING & POWER
               MS7001C APRIL 1978

TEST PT       BASE-OIL                      OUTPUT      ~65.00   MW
DATE          780421                        NOX         148.3    PPMV(WET)
TIME          9999      HOURS               NOX(ISO)    152.0    PPMV(WET)
BAROMETER     29.740    INS.HG.             NO          142.5    PPMV(WET)
T (DRY)       69.4      DEG.F.              NO(ISO)     145.1    PPMV(WET)  EMISSIONS
T (WET)       57.4      DEG.F.  AMBIENT     O2           15.50   VOL.(DRY)
REL.HUM.      48.0      %       CONDITIONS  CO2           3.97   VOL.(DRY)
ABS.HUM.      0.0074    LBS/LB              CO            5.0    PPMV(DRY)
CDP           147.6     PSIA                UHC           5.0    PPMV(WET) CH4
CDT           623.0     DEG.F.              H2O (INJECTION) 0.   GPM
T.G.V.        77.0      DEG.F.              FUEL         10.768  PPS
COMP.EFF.               %                   WATER/FUEL    0.     LBS/LB
COMB.EFF.     99.70     %                   FBN FUEL BOUND 0.008 % BY WT.
                                                NITROGEN

                    FT.TEST       CHKD.         OXYGEN        CO2
                    FLOW          FLOW          CONC.         CONC.
WEX(DRY) MSCF/HR    26.2232       26.4343       26.5362       26.9209 — EXHAUST FLOW (10^6 STD FT³/HR)
WA            PPS   570.3         574.8         576.9         585.3 —— COMPRESSOR INLET FLOW (lbm/sec)
WA(ISO)       PPS   589.6         594.2         596.4         605.1    "      "   "  AT ISO AMBIENT (lbm/sec)
T FIR       DEG.F
T NOZ       DEG.F
H2O   % OF COMP.    0.            0.            0.            0.  —— WATER INJECTION RATE (% OF WA)
F/A                 0.0109        0.0107        0.0107        0.0104 — MACHINE FUEL AIR RATIO
NOX           PPM   494.2         498.0         499.9         507.0 } NOx (lbm/hr)
NOX(ISO)      PPM   506.6         510.7         512.6         519.9 }
NOX  15% O2 DRY     173.3         173.4         174.0         176.4 —— ISO NOx @ 15% O2 (ppmv, dry)
NOX PPMBTU INPUT    0.65          0.66          0.66          0.67 } NOx (lbm/ 10^6 BTU)
NOX(ISO) PPMBTU     0.67          0.68          0.68          0.69 }
EI NOX PPTP FUEL    12.6          12.9          12.9          13.1 } EMISSION INDEX (lbm NOx / 10^3 lbm fuel)
EI NOX(ISO)         13.1          13.2          13.2          13.4 }
ORG.NOX 100% YLD    1.5           1.5           1.5           1.5 - ORGANIC NOx (ppmv), at 100% yield of fuel bound nitrogen
O2 CONC %VOL.DRY    15.48         15.48         15.50         15.58 } exhaust gas composition
CO2    % VOL DRY    4.07          4.04          4.03          3.97  }
CO AT 15% O2 DRY    5.4           5.4           5.5           5.5  } CO
EI CO  PPTP FUEL    0.26          0.26          0.26          0.27 }
SO2      PPMV DRY   19.1          19.1          19.0          18.8 - CALCULATED SO2, at 100% conversion of fuel sulfur
DRY TO WET    VOL   1.049         1.049         1.049         1.048 - exhaust moisture correction
MW(EXHAUST)         [illegible]   28.87         28.86         28.86 - mean molecular weight of exhaust gas
COMB. DP/P %
```

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TABLE 4

```
                        06/09/78   12.08HOURS
                        FIRCAL9 REVISED 03/30/78
                     HOUSTON LIGHTING & POWER
                     MS7001C APRIL 1978

TEST PT        3D-61MW                       OUTPUT      61.00     MW
DATE           780422                        NOX        133.8      PPMV(WET)
TIME           1657     HOURS                NOX(ISO)   159.8      PPMV(WET)
BAROMETER      29.740   INS.HG.              NO         126.1      PPMV(WET)
T (DRY)        74.8     DEG.F.               NO(ISO)    152.1      PPMV(WET)
T (WET)        69.1     DEG.F.               O2          15.20     VOL.(DRY)
REL.HUM.       77.0     %                    CO2          4.09     VOL.(DRY)
ABS.HUM.        0.0142  LBS/LB               CO           6.3      PPMV(DRY)
CDP           145.5     PSIA                 UHC          2.5      PPMV(WET)CH4
CDT           612.0     DEG.F.               H2O          0.       GPM
I.G.V.         77.0     DEG.F.               FUEL        10.857    PPS
COMP.EFF.      86.94  %                      WATER/FUEL  0.        LBS/LB
COMB.EFF.      99.90  %                      FBN          0.004    % BY WT.

                      FT.TEST        CMKD.         OXYGEN          CO2
                       FLOW          FLOW          CONC.          CONC.
WEX(DRY) MSCF/HR      25.7320       25.8843       25.3607        26.3499
WA            PPS    563.7         562.0         555.7          576.9
WA(ISO)       PPS    589.6         593.0         581.2          603.4


H2O   % OF COMP.       0.            0.            0.             0.
F/A                    0.0193        0.0191        0.0195         0.0188
NOX           PPH    440.2         442.7         484.0          450.4
NOX(ISO)      PPH    528.9         531.9         521.5          541.1
NOX   15% O2 DRY     180.7         179.1         175.6          182.2
NOX PPMBTU INPUT       0.58          0.58          0.57           0.59
NOX(ISO) PPMBTU        0.69          0.70          0.68           0.71
EI NOX PPTP FUEL      11.3          11.3          11.1           11.5
EI NOX(ISO)           13.5          13.6          13.3           13.8
ORG.NOX 100% YLD       1.6           1.5           1.6            1.5
O2 CONC %VOL.DRY      15.37         15.32         15.20          15.42
CO2    % VOL DRY       4.19          4.16          4.25           4.09
CO AT 15% O2 DRY       6.7           6.7           6.5            6.8
EI CO  PPTP FUEL       0.32          0.33          0.32           0.33
SO2     PPMV DRY      19.5          19.7          20.1           19.3
DRY TO WET   VOL       1.062         1.061         1.062          1.061
MMW(EXHAUST)          28.75         28.75         28.75          28.75
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TABLE 5

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                      06/09/78   12.08HOURS
                      FIRCAL9 REVISED 03/30/78
                   HOUSTON LIGHING & POWER
                   MS7001C APRIL 1978

TEST PT        4D-62MW                           OUTPUT       62.00    MW
DATE           780422                            NOX         131.5     PPMV(WET)
TIME           1802     HOURS                    NOX(ISO)    259.0     PPMV(WET)
BAROMETER      29.780   INS.HG.                  NO          125.5     PPMV(WET)
T (DRY)        71.2     DEG.F.                   NO(ISO)     151.1     PPMV(WET)
T (WET)        68.5     DEG.F.                   O2           15.30    VOL.(DRY)
REL.HUM.       87.5     %                        CO2           4.09    VOL.(DRY)
ABS.HUM.        0.0144  LBS/LB                   CO            6.0     PPMV(DRY)
CDP           146.5     PSIA                     UHC           2.0     PPMV(WET)CH4
CDT           609.0     DEG.F.                   H2O           0.      GPM
I.G.V.         77.0     DEG.F.                   FUEL         10.925   PPS
COMP.EFF.      86.65  %                          WATER/FUEL    0.      LBS/LB
COMB.EFF.      99.90  %                          FBN           0.004   % BY WT.

                          FT.TEST        CHKD.         OXYGEN         CO2
                           FLOW          FLOW          CONC.          CONC.
WEX(DRY) MSCF/HR          25.9521       26.0627       25.9706        26.5142
WA               PPS     568.7         571.0         569.0          580.7
WA(ISO)          PPS     589.6         592.0         589.9          602.0


H2O    % OF COMP.          0.            0.            0.             0.
F/A                        0.0192        0.0191        0.0192         0.0188
NOX              PPH     439.1         440.9         439.4          448.2
NOX(ISO)         PPH     530.8         532.9         531.1          541.8
NOX    15% O2 DRY        177.7         178.4         177.7          181.3
NOX PPMBTU INPUT           0.59          0.57          0.57           0.58
NOX(ISO) PPMBTU            0.69          0.69          0.69           0.71
EI NOX PPTP FUEL          11.2          11.2          11.2           11.4
EI NOX(ISO)               13.5          13.6          13.5           13.8
ORG.NOX 100% YLD           1.5           1.5           1.5            1.5
O2 CONC %VOL.DRY          15.30         15.32         15.30          15.42
CO2     % VOL DRY          4.10          4.16          4.11           4.09
CO AT 15% O2 DRY           6.3           6.3           6.3            6.4
EI CO  PPTP FUEL           0.31          0.31          0.31           0.32
SO2      PPMV DRY         19.7          19.7          19.7           19.3
DRY TO WET   VOL           1.062         1.062         1.062          1.061
MMW(EXHAUST)              28.75         28.75         28.74          28.74
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TABLE 6

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                      06/09/78   12.08HOURS
                      FINCAL9 REVISED 03/30/78
                    HOUSTON LIGHING & POWER
                    MS7001C APRIL 1978

TEST PT        5D-62MW                      OUTPUT        62.00     MW
DATE           780422                       NOX           140.3     PPMV(WET)
TIME           2000      HOURS              NOX(ISO)      159.2     PPMV(WET)
BAROMETER      29.800    INS.HG.            NO            132.3     PPMV(WET)
T (DRY)        67.0      DEG.F.             NO(ISO)       150.6     PPMV(WET)
T (WET)        63.6      DEG.F.             O2             15.50    VOL.(DRY)
REL.HUM.       83.6      %                  CO2             4.16    VOL.(DRY)
ABS.HUM.        0.0119   LBS/LB             CO              6.0     PPMV(DRY)
CDP           148.8      PSIA               UHC             1.0     PPMV(WET)CH4
CDT           605.0      DEG.F.             H2O             0.      GPM
I.G.V.         77.0      DEG.F.             FUEL           11.098   PPS
COMP.EFF.      86.82  %                     WATER/FUEL      0.      LBS/LB
COMB.EFF.      99.90  %                     FBN             0.004   % BY WT.

                        FT.TEST        CMKD.        OXYGEN         CO2
                         FLOW          FLOW          CONC.        CONC.
WEX(DRY) MSCF/HR        26.2897       25.5805       27.3816      26.4798
WA              PPS    574.6         580.8         597.3        578.6
WA(ISO)         PPS    589.6         596.0         612.9        593.7

H20    % OF COMP.        0.            0.            0.           0.
F/A                      0.0193        0.0191        0.0186       0.0192
NOX             PPH    472.9         471.5         490.9        475.8
NOX(ISO)        PPH    538.0         545.6         558.8        541.6
NOX   15% O2 DRY       176.8         179.1         184.0        178.4
NOX PPMBTU INPUT         0.61          0.61          0.63         0.61
NOX(ISO) PPMBTU          0.69          0.70          0.72         0.70
EI NOX PPTP FUEL        11.8          12.0          12.3         11.9
EI NOX(ISO)             13.5          13.6          14.0         13.6
ORG.NOX 100% YLD         1.6           1.5           1.5          1.5
O2 CONC %VOL.DRY        15.27         15.34         15.50        15.32
CO2    % VOL DRY         4.19          4.14          4.03         4.16
CO AT 15% O2 DRY         6.3           6.4           6.5          6.3
EI CO   PPTP FUEL        0.31          0.31          0.32         0.31
SO2       PPMV DRY      19.9          19.6          19.0         19.7
DRY TO WET    VOL        1.058         1.057         1.056        1.058
MMW(EXHAUST)            28.79         28.79         28.79        28.79
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TABLE 7

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                          06/07/78   12.08HOURS
                          FIRCAL9 REVISED 03/30/78
                        HOUSTON LIGHTING & POWER
                        MS7001C APRIL 1978

TEST PT      6D-62MW                       OUTPUT       62.00    MW
DATE         780422                        NOX         131.0     PPMV(WET)
TIME         2101     HOURS                NOX(ISO)    157.4     PPMV(WET)
BAROMETER    29.620   INS.HG.              NO          124.5     PPMV(WET)
T (DRY)      71.0     DEG.F.               NO(ISO)     149.6     PPMV(WET)
T (WET)      68.0     DEG.F.               O2           15.20    VOL.(DRY)
REL.HUM.     86.1     %                    CO2           4.08    VOL.(DRY)
ABS.HUM.      0.0142  LBS/LB               CO            6.0     PPMV(DRY)
CDP         146.5     PSIA                 UHC           1.0     PPMV(WET)CH4
CDT         607.0     DEG.F.               H2O           0.      GPM
I.G.V.       77.0     DEG.F.               FUEL         10.917   PPS
COMP.EFF.    87.23  %                      WATER/FUEL    0.      LBS/LB
COMB.EFF.    99.90  %                      FBN           0.004   % BY WT.

                         FT.TEST        CHKD.         OXYGEN        CO2
                          FLOW          FLOW          CONC.         CONC.
WEX(DRY) MSCF/HR         25.8285       26.0970       25.4991       26.5590
WA              PPS     565.9         571.6         558.7         581.9
WA(ISO)         PPS     589.6         595.6         582.1         605.9


H2O   % OF COMP.          0.            0.            0.            0.
F/A                       0.0193        0.0191        0.0195        0.0188
NOX             PPH     435.3         439.6         429.9         447.1
NOX(ISO)        PPH     523.1         528.3         516.6         537.3
NOX   15% O2 DRY        175.6         176.9         173.0         179.9
NOX PPMBTU INPUT          0.57          0.57          0.56          0.58
NOX(ISO) PPMBTU           0.68          0.69          0.67          0.70
EI NOX PPTP FUEL         11.1          11.2          10.9          11.4
EI NOX(ISO)              13.3          13.4          13.1          13.7
ORG.NOX 100% YLD          1.6           1.5           1.6           1.5
O2 CONC %VOL.DRY         15.29         15.33         15.20         15.43
CO2    % VOL DRY          4.19          4.15          4.25          4.08
CO AT 15% O2 DRY          6.3           6.4           6.2           6.5
EI CO  PPTP FUEL          0.31          0.31          0.30          0.32
SO2      PPMV DRY        19.8          19.6          20.1          19.3
DRY TO WET   VOL          1.062         1.061         1.062         1.061
MMW(EXHAUST)             28.75         28.75         28.75         28.75
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TABLE 8

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                         06/09/78   12.08HOURS
                       FIRCAL9 REVISED 03/30/78
                     HOUSTON LIGHING & POWER
                     MS7001C APRIL 1978

TEST PT       7D-63MW                        OUTPUT       63.00    MW
DATE          780422                         NOX         132.8     PPMV(WET)
TIME          2200      HOURS                NOX(ISO)    160.3     PPMV(WET)
BAROMETER     29.120    INS.HG.              NO          125.5     PPMV(WET)
T (DRY)       70.0      DEG.F.               NO(ISO)     151.5     PPMV(WET)
T (WET)       68.0      DEG.F.               O2           15.30    VOL.(DRY)
REL.HUM.      90.5      %                    CO2           4.00    VOL.(DRY)
ABS.HUM.       0.0144   LBS/LB               CO            6.0     PPMV(DRY)
CDP          146.7      PSIA                 UHC           1.0     PPMV(WET)CH4
CDT          608.0      DEG.F.               H2O           0.      GPM
I.G.V.        77.0      DEG.F.               FUEL         10.985   PPS
COMP.EFF.     86.63  %                       WATER/FUEL    0.      LBS/LB
COMB.EFF.     99.90  %                       FBN           0.004   % BY WT.

                      FT.TEST        CHKD.         OXYGEN         CO2
                       FLOW          FLOW          CONC.          CONC.
WEX(DRY) MSCF/HR      25.9708       28.0855       26.1132        27.2634
WA             PPS    569.1         571.6         572.1          596.8
WA(ISO)        PPS    589.6         592.1         592.7          618.3

H2O   % OF COMP.      0.            0.            0.             0.
F/A                   0.0193        0.0192        0.0192         0.0184
NOX            PPH    443.8         445.6         446.1          465.0
NOX(ISO)       PPH    535.6         537.8         538.4          561.2
NOX   15% O2 DRY      178.3         179.0         179.1          186.7
NOX PPMBTU INPUT      0.58          0.58          0.58           0.60
NOX(ISO) PPMBTU       0.69          0.70          0.70           0.73
EI NOX PPTP FUEL      11.2          11.3          11.3           11.8
EI NOX(ISO)           13.5          13.6          13.6           14.2
ORG.NOX 100% YLD      1.6           1.5           1.5            1.5
O2 CONC %VOL.DRY      15.29         15.30         15.30          15.54
CO2     % VOL DRY     4.20          4.18          4.17           4.00
CO AT 15% O2 DRY      6.3           6.3           6.3            6.6
EI CO  PPTP FUEL      0.31          0.31          0.31           0.32
SO2      PPMV DRY     19.8          19.8          19.7           18.9
DRY TO WET    VOL     1.062         1.062         1.062          1.060
MMW(EXHAUST)          28.75         28.75         28.74          28.74
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TABLE 9

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                           06/07/78   12.08HOURS
                           FIRCAL9 REVISED 03/30/78
                         HOUSTON LIGHTING & POWER
                         MS7001C APRIL 1978

TEST PT       8D-62MW                            OUTPUT      62.00    MW
DATE          780422                             NOX        133.0     PPMV(WET)
TIME          2255     HOURS                     NOX(ISO)   158.6     PPMV(WET)
BAROMETER     29.760   INS.HG.                   NO         126.7     PPMV(WET)
T (DRY)       73.0     DEG.F.                    NO(ISO)    151.1     PPMV(WET)
T (WET)       68.5     DEG.F.                    O2          15.30    VOL.(DRY)
REL.HUM.      76.8     %                         CO2          4.09    VOL.(DRY)
ABS.HUM.       0.0138  LBS/LB                    CO           6.0     PPMV(DRY)
CDP          146.5     PSIA                      UHC          1.0     PPMV(WET)CH4
CDT          609.0     DEG.F.                    H2O          0.      GPM
I.G.V.        77.0     DEG.F.                    FUEL        10.951   PPS
COMP.EFF.     87.56  %                           WATER/FUEL   0.      LBS/LB
COMB.EFF.     99.90  %                           FBN          0.004   % BY WT.

                       FT.TEST        CHKD.          OXYGEN          CO2
                        FLOW          FLOW           CONC.           CONC.
WEX(DRY) MSCF/HR       25.7914        26.0546        26.0320         26.5767
WA             PPS    564.9          570.6          570.0           581.7
WA(ISO)        PPS    589.6          595.5          594.9           607.1

H20    % OF COMP.       0.             0.             0.              0.
F/A                     0.0194         0.0192         0.0192          0.0188
NOX            PPM    441.1          445.4          445.0           454.0
NOX(ISO)       PPM    525.9          531.0          530.6           541.3
NOX    15% O2 DRY     175.5          177.3          177.1           180.7
NOX PPMBTU INPUT        0.57           0.58           0.58            0.59
NOX(ISO) PPMBTU         0.68           0.69           0.69            0.70
EI NOX PPTP FUEL       11.2           11.3           11.3            11.5
EI NOX(ISO)            13.3           13.5           13.5            13.7
ORG.NOX 100% YLD        1.6            1.5            1.5             1.5
O2 CONC %VOL.DRY       15.25          15.31          15.30           15.42
CO2      % VOL DRY      4.21           4.17           4.12            4.09
CO AT 15% O2 DRY        6.3            6.3            6.3             6.4
EI CO   PPTP FUEL       0.31           0.31           0.31            0.32
SO2       PPMV DRY     19.9           19.7           19.7            19.3
DRY TO WET     VOL      1.061          1.061          1.061           1.060
MMW(EXHAUST)           28.76          28.76          28.75           28.75
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TABLE 10

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                          06/06/78   13.81HOURS
                          FIRCAL9 REVISED 03/30/78
                       HOUSTON LIGHING & POWER
                       MS7001C APRIL 1978

TEST PT     .9D-60MW                          OUTPUT       60.00     MW
DATE         780424                           NOX          135.8     PPMV(WET)
TIME         1309     HOURS                   NOX(ISO)     158.7     PPMV(WET)
BAROMETER    29.850   INS.HG.                 NO           130.1     PPMV(WET)
T (DRY)      83.8     DEG.F.                  NO(ISO)      152.1     PPMV(WET)
T (WET)      70.2     DEG.F.                  O2            15.46    VOL.(DRY)
REL.HUM.     53.5     %                       CO2            3.94    VOL.(DRY)
ABS.HUM.      0.0130  LBS/LB                  CO             5.5     PPMV(DRY)
CDP         144.1     PSIA                    UHC            4.1     PPMV(WET)CH4
CDT         619.0     DEG.F                   H2O            0.      GPM
I.G.V.       77.0     DEG.F                   FUEL          10.546   PPS
COMP.EFF.    87.88  %                         WATER/FUEL   0.        LBS/LB
COMB.EFF.    99.90  %                         FBN            0.008   % BY WT.

                      FT.TEST        CWKD.         OXYGEN          CO2
                       FLOW          FLOW           CONC.          CONC.
WEX(DRY) MSCF/HR      25.3430       25.7001        25.8698        26.5054
WA            PPS    554.5         562.2          565.8          579.5
WA(ISO)       PPS    589.6         597.7          601.6          616.1

H2O   % OF COMP        0.            0.             0.             0.
F/A                    0.0190        0.0188         0.0186         0.0182
NOX           PPH    441.9         447.9          450.7          461.4
NOX(ISO)      PPH    516.5         525.4          526.8          539.2
NOX   15% O2 DRY     180.9         180.9          182.0          186.3
NOX PPMBTU INPUT       0.59          0.60           0.60           0.62
NOX(ISO) PPMBTU        0.69          0.70           0.70           0.72
EI NOX PPTP FUEL      11.6          11.8           11.9           12.2
EI NOX(ISO)           13.6          13.8           13.9           14.2
ORG.NOX 100% YLD       3.1           3.0            3.0            2.9
O2 CONC %VOL.DRY      15.42         15.43          15.46          15.59
CO2     % VOL DRY      4.12          4.06           4.04           3.94
CO AT 15% O2 DRY       5.9           5.9            5.9            6.1
EI CO   PPTP FUEL      0.29          0.29           0.29           0.30
SO2       PPMV DRY    19.3          19.3           19.1           18.7
DRY TO WET    VOL      1.060         1.059          1.059          1.058
MMW(EXHAUST)          28.76         28.76          28.76          28.76
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TABLE 11

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                     06/06/78   13.81HOURS
                     FIRCAL9 REVISED 03/30/78
                  HOUSTON LIGHING & POWER
                  MS7001C APRIL 1978

 TEST PT       10D-60MW-20GPM                 OUTPUT        60.00    MW
 DATE          780424                         NOX            89.7    PPMV(WET)
 TIME          1408     HOURS                 NOX(ISO)      106.6    PPMV(WET)
 BAROMETER     29.830   INS.HG.               NO             84.0    PPMV(WET)
 T (DRY)       84.5     DEG.F.                NO(ISO)        99.8    PPMV(WET)
 T (WET)       71.5     DEG.F.                O2            15.29    VOL.(DRY)
 REL.HUM.      53.6     %                     CO2            3.85    VOL.(DRY)
 ABS.HUM.       0.0137  LBS/LB                CO              6.1    PPMV(DRY)
 CDP          144.8     PSIA                  UHC             2.9    PPMV(WET)CH4
 CDT          624.0     DEG.F.                H2O            20.0    GPM
 T.G.V.        77.0     DEG.F.                FUEL         10.768    PPS
 COMP.EFF.     87.74  %                       WATER/FUEL     0.26    LBS/LB
 COMB.EFF.     99.90  %                       FBN           0.008    % BY WT.

                         FT.TEST         CHKD.          OXYGEN          CO2
                          FLOW           FLOW           CONC.          CONC.
 WEX(DRY) MSCF/HR        25.2109        25.6333        25.7423        27.8290
 WA            PPS      552.2          561.3          563.8          608.7
 WA(ISO)       PPS      589.6          599.3          602.0          649.8

 H2O   % OF COMP.         0.50           0.50           0.49           0.46
 F/A                      0.0195         0.0192         0.0191         0.0177
 NOX           PPH      293.3          298.0          299.2          322.4
 NOX(ISO)      PPH      348.5          354.0          355.4          383.0
 NOX   15% O2 DRY       117.5          119.3          119.8          129.8
 NOX PPMBTU INPUT         0.38           0.39           0.39           0.42
 NOX(ISO) PPMBTU          0.46           0.46           0.47           0.50
 EI NOX PPTP FUEL         7.6            7.7            7.7            8.3
 EI NOX(ISO)              9.0            9.1            9.2            9.9
 ORG.NOX 100% YLD         3.1            3.1            3.1            2.8
 O2 CONC %VOL.DRY        15.17          15.27          15.29          15.72
 CO2     % VOL DRY        4.25           4.18           4.16           3.85
 CO AT 15% O2 DRY         6.3            6.4            6.4            6.9
 EI CO   PPTP FUEL        0.31           0.32           0.32           0.34
 SO2      PPMV DRY       20.1           19.8           19.7           18.2
 DRY TO WET   VOL         1.071          1.070          1.070          1.066
 MMW(EXHAUST)            28.65          28.65          28.66          28.67
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TABLE 12

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                    06/06/78   13.81HOURS
                    FIRCAL9 REVISED 03/30/78
                  HOUSTON LIGHING & POWER
                  MS7001C APRIL 1978

 TEST PT      11D-61MW-40GPM               OUTPUT      61.00    MW
 DATE         780424                       NOX         57.5     PPMV(WET)
 TIME         1500     HOURS               NOX(ISO)    67.8     PPMV(WET)
 BAROMETER    29.810   INS.HG.             NO          53.4     PPMV(WET)
 T (DRY)      85.0     DEG.F.              NO(ISO)     62.9     PPMV(WET)
 T (WET)      71.2     DEG.F.              O2          15.14    VOL.(DRY)
 REL.HUM.     51.4     %                   CO2          4.00    VOL.(DRY)
 ABS.HUM.      0.0133  LBS/LB              CO           7.9     PPMV(DRY)
 CDP         145.1     PSIA                UHC          4.3     PPMV(WET)CH4
 CDT         627.0     DEG.F.              H2O         40.0     GPM
 T.G.V.       77.0     DEG.F.              FUEL        10.955   PPS
 COMP.EFF.    87.52  %                     WATER/FUEL   0.51    LBS/LB
 COMB.EFF.    99.90  %                     FBN          0.008   % BY WT.

                       FT.TEST       CMKD.        OXYGEN        CO2
                        FLOW         FLOW          CONC.        CONC.
 WEX(DRY) MSCF/HR      25.1864      25.5431       25.6357      27.3753
 WA            PPS     551.2        559.3         561.7        599.1
 WA(ISO)       PPS     589.6        598.2         600.8        640.7

 H2O    % OF COMP       1.01         0.99          0.99         0.93
 F/A                    0.0199       0.0196        0.0195       0.0183
 NOX           PPH    189.4        192.1         192.8        205.1
 NOX(ISO)      PPH    223.2        226.4         227.1        241.7
 NOX    15% O2 DRY     73.5         74.6          74.9         79.7
 NOX PPMBTU INPUT       0.24         0.25          0.25         0.26
 NOX(ISO) PPMBTU        0.29         0.29          0.29         0.31
 EI NOX PPTP FUEL       4.8          4.9           4.9          5.2
 EI NOX(ISO)            5.7          5.7           5.8          6.1
 ORG.NOX 100% YLD       3.1          3.1           3.1          2.9
 O2 CONC %VOL.DRY      15.03        15.12         15.14        15.52
 CO2     % VOL DRY      4.35         4.29          4.27         4.00
 CO AT 15% O2 DRY       7.9          8.0           8.0          8.6
 EI CO   PPTP FUEL      0.40         0.40          0.41         0.43
 SO2      PPMV DRY     20.6         20.3          20.2         18.9
 DRY TO WET    VOL      1.080        1.079         1.079        1.075
 MMW(EXHAUST)          28.56        28.56         28.58        28.59
```

TABLE 13

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                        06/06/78    13.81HOURS
                        FIRCAL9 REVISED 03/30/78
                      HOUSTON LIGHING & POWER
                      MS7001C APRIL 1978

 TEST PT       12D-61MW-40GPM              OUTPUT        61.00    MW
 DATE          780424                      NOX           57.8     PPMV(WET)
 TIME          1600     HOURS              NOX(ISO)      67.8     PPMV(WET)
 BAROMETER     29.790   INS.HG.            NO            53.7     PPMV(WET)
 T (DRY)       83.5     DEG.F.             NO(ISO)       63.0     PPMV(WET)
 T (WET)       70.5     DEG.F.             O2            15.13    VOL.(DRY)
 REL.HUM.      53.1     %                  CO2            3.92    VOL.(DRY)
 ABS.HUM.       0.0131  LBS/LB             CO             8.1     PPMV(DRY)
 CDP          144.7     PSIA               UHC            2.4     PPMV(WET)CH4
 CDT          626.0     DEG.F.             H20           40.0     GPM
 T.G.V.        77.0     DEG.F.             FUEL          10.981   PPS
 COMP.EFF.     87.11  %                    WATER/FUEL     0.51    LBS/LB
 COMB.EFF.     99.90  %                    FBN            0.008   % BY WT.

                         FT.TEST         CHKD.         OXYGEN          CO2
                          FLOW           FLOW           CONC.          CONC.
 WEX(DRY) MSCF/HR        25.2426        25.4344        25.6521        28.0028
 WA            PPS      552.8          558.9          562.0          612.4
 WA(ISO)       PPS      589.6          594.0          599.4          653.2


 H20    % OF COMP.        1.01           1.00           0.99           0.91
 F/A                      0.0199         0.0197         0.0195         0.0179
 NOX           PPH      190.9          192.2          193.8          210.6
 NOX(ISO)      PPH      223.9          225.5          227.3          247.0
 NOX    15% O2 DRY       73.6           74.1           74.8           81.3
 NOX PPMBTU INPUT         0.25           0.25           0.25           0.27
 NOX(ISO) PPMBTU          0.29           0.29           0.29           0.32
 EI NOX PPTP FUEL         4.8            4.9            4.9            5.3
 EI NOX(ISO)              5.7            5.7            5.8            6.2
 ORG.NOX 100% YLD         3.1            3.1            3.1            2.9
 O2 CONC %VOL.DRY        15.03          15.08          15.13          15.62
 CO2     % VOL DRY        4.35           4.32           4.28           3.92
 CO AT 15% O2 DRY         8.1            8.2            8.3            9.0
 EI CO   PPTP FUEL        0.41           0.41           0.42           0.45
 SO2      PPMV DRY       20.6           20.5           20.3           18.6
 DRY TO WET   VOL         1.079          1.079          1.078          1.074
 MMW(EXHAUST)            28.56          28.57          28.59          28.60
```

TABLE 14

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                       06706/78   13.81HOURS
                       FIRCAL9 REVISED 03/30/78
                     HOUSTON LIGHING & POWER
                     MS7001C APRIL 1978

 TEST PT       13D-61MW-40GPM                 OUTPUT         61.00     MW
 DATE          780424                         NOX            57.6      PPMV(WET)
 TIME          1700      HOURS                NOX(ISO)       67.6      PPMV(WET)
 BAROMETER     29.780    INS.HG.              NO             53.6      PPMV(WET)
 T (DRY)       83.3      DEG.F.               NO(ISO)        62.9      PPMV(WET)
 T (WET)       70.5      DEG.F.               O2             15.14     VOL.(DRY)
 REL.HUM.      53.6      %                    CO2             3.93     VOL.(DRY)
 ABS.HUM.       0.0132   LBS/LB               CO              7.8      PPMV(DRY)
 CDP          144.5      PSIA                 UHC             4.1      PPMV(WET)CH4
 CDT          628.0      DEG.F.               H2O            40.0      GPM
 I.G.V.        77.0      DEG.F.               FUEL           10.944    PPS
 COMP.EFF.     86.64  %                       WATER/FUEL      0.51     LBS/LB
 COMB.EFF.     99.90  %                       FBN             0.008    % BY WT

                       FT.TEST          CHKD.           OXYGEN          CO2
                        FLOW            FLOW            CONC.          CONC.
 WEX(DRY) MSCF/HR      25.2463         25.4035         25.6080        27.8356
 WA            PPS    552.9           556.2           561.0          608.8
 WA(ISO)       PPS    589.6           593.2           598.3          649.3


 H2O   % OF COMP.       1.01            1.00            0.99           0.91
 F/A                    0.0198          0.0197          0.0195         0.0180
 NOX           PPH    190.1           191.2           192.7          208.5
 NOX(ISO)      PPH    223.3           224.6           226.3          244.9
 NOX   15% O2 DRY      74.6            75.1            74.7           80.9
 NOX PPMBTU INPUT       0.25            0.25            0.25           0.27
 NOX(ISO) PPMBTU        0.29            0.29            0.29           0.32
 EI NOX PPTP FUEL       4.8             4.9             4.9            5.3
 EI NOX(ISO)            5.7             5.7             5.7            6.2
 ORG.NOX 100% YLD       3.1             3.1             3.1            2.9
 O2 CONC %VOL.DRY      15.13           15.09           15.14          15.61
 CO2     % VOL DRY      4.33            4.31            4.27           3.93
 CO AT 15% O2 DRY       8.0             7.9             8.0            8.7
 EI CO   PPTP FUEL      0.40            0.40            0.40           0.44
 SO2      PPMV DRY     20.3            20.4            20.2           18.6
 DRY TO WET   VOL       1.079           1.079           1.078          1.074
 MMW(EXHAUST)          28.56           28.56           28.59          28.60
```

TABLE 15

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                         06/08/78   13.81HOURS
                         FIRCAL9 REVISED 03/30/78
                      HOUSTON LIGHING & POWER
                      MS7001C APRIL 1978

TEST PT        14D-61.5MW*40GPM            OUTPUT       61.50     MW
DATE           780424                      NOX          55.8      PPMV(WET)
TIME           1800      HOURS             NOX(ISO)     66.9      PPMV(WET)
BAROMETER      29.780    INS.HG.           NO           51.8      PPMV(WET)
T (DRY)        81.2      DEG.F.            NO(ISO)      62.1      PPMV(WET)
T (WET)        71.0      DEG.F.            O2           15.10     VOL.(DRY)
REL.HUM.       61.2      %                 CO2           3.87     VOL.(DRY)
ABS.HUM.        0.0141   LBS/LB            CO            8.0      PPMV(DRY)
CDP           145.4      PSIA              UHC           4.1      PPMV(WET)CH4
CDT           624.8      DEG.F.            H2O          40.0      GPM
I.G.V.         77.0      DEG.F.            FUEL         11.054    PPS
COMP.EFF.      86.93  %                    WATER/FUEL    0.50     LBS/LB
COMB.EFF.      99.90  %                    FBN           0.008    % BY WT.

                        FT.TEST        CHKD.         OXYGEN          CO2
                         FLOW          FLOW          CONC.          CONC.
WEX(DRY) MSCF/HR        25.3440       25.5269       25.6873        28.5513
WA            PPS      555.6         559.5         563.3          624.9
WA(ISO)       PPS      589.6         593.8         597.8          663.1


H2O   % OF COMP.         1.00          0.99          0.99           0.89
F/A                      0.0199        0.0198        0.0196         0.0177
NOX           PPH      185.2         186.5         187.6          207.4
NOX(ISO)      PPH      222.0         223.5         224.8          248.6
NOx   15% O2 DRY        73.5          73.0          73.5           81.3
NOX PPMBTU INPUT         0.24          0.24          0.24           0.26
NOX(ISO) PPMBTU          0.28          0.29          0.29           0.32
EI NOX PPTP FUEL         4.7           4.7           4.7            5.2
EI NOX(ISO)              5.6           5.6           5.7            6.2
ORG.NOX 100% YLD         3.1           3.1           3.1            2.8
O2 CONC %VOL.DRY        15.10         15.06         15.10          15.69
CO2     % VOL DRY        4.36          4.33          4.30           3.87
CO AT 15% O2 DRY         8.2           8.1           8.2            9.1
EI CO   PPTP FUEL        0.41          0.41          0.41           0.46
SO2        PPMV DRY     20.4          20.5          20.4           18.3
DRY TO WET    VOL        1.081         1.081         1.080          1.074
MMW(EXHAUST)            28.55         28.55         28.57          28.59
```

TABLE 16

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                          06/08/78   13.81HOURS
                          FIRCAL9 REVISED 03/30/78
                        HOUSTON LIGHING & POWER
                        MS7001C APRIL 1978

TEST PT      15D-63MW-40GPM             OUTPUT      63.00    MW
DATE         780424                     NOX         56.1     PPMV(WET)
TIME         1900     HOURS             NOX(ISO)    68.5     PPMV(WET)
BAROMETER    29.780   INS.HG.           NO          51.9     PPMV(WET)
T (DRY)      77.0     DEG.F.            NO(ISO)     63.4     PPMV(WET)
T (WET)      70.8     DEG.F.            O2          15.07    VOL.(DRY)
REL.HUM.     74.2     %                 CO2          3.98    VOL.(DRY)
ABS.HUM.      0.0149 LBS/LB             CO           7.9     PPMV(DRY)
CDP         146.8     PSIA              UHC          2.8     PPMV(WET)CH4
CDT         616.0     DEG.F.            H2O         40.0     GPM
T.G.V.       77.0     DEG.F.            FUEL        11.244   PPS
COMP,EFF.    87.42  %                   WATER/FUEL   0.49    LBS/LB
COMB.EFF.    99.90  %                   FBN          0.008   % BY WT.

                     FT.TEST      CHKD.        OXYGEN        CO2
                      FLOW        FLOW         CONC.        CONC.
WEX(DRY) MSCF/HR     25.5687     25.7321      25.9913      28.2305
WA           PPS    561.0       564.6        570.5        618.7
WA(ISO)      PPS    589.6       593.3        599.6        650.1


H2O   % OF COMP.      0.99        0.98         0.97         0.90
F/A                   0.0200      0.0199       0.0197       0.0182
NOX          PPH    188.1       189.2        191.0        206.6
NOX(ISO)     PPH    229.8       231.2        233.4        252.4
NOX   15% O2 DRY     74.9        75.3         75.0         81.1
NOX PPMBTU INPUT      0.24        0.24         0.24         0.26
NOX(ISO) PPMBTU       0.29        0.29         0.29         0.32
EI NOX PPTP FUEL      4.6         4.7          4.7          5.1
EI NOX(ISO)           5.7         5.7          5.8          6.2
ORG.NOX 100% YLD      3.2         3.2          3.1          2.9
O2 CONC %VOL.DRY     15.06       15.01        15.07        15.54
CO2    % VOL DRY      4.39        4.37         4.32         3.98
CO AT 15% O2 DRY      8.0         7.9          8.0          8.7
EI CO  PPTP FUEL      0.40        0.40         0.41         0.44
SO2      PPMV DRY    20.5        20.7         20.5         18.9
DRY TO WET    VOL     1.083       1.082        1.082        1.077
MMW(EXHAUST)         28.54       28.54        28.56        28.57
```

TABLE 17

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                        06/06/78   13.81HOURS
                        PIRCAL9 REVISED 03/30/78
                      HOUSTON LIGHING & POWER
                      MS7001C APRIL 1978

TEST PT       16D-62MW                           OUTPUT       62.00     MW
DATE          780424                             NOX         130.8      PPMV(WET)
TIME          2000      HOURS                    NOX(ISO)    158.3      PPMV(WET)
BAROMETER     29.820    INS.HG.                  NO          123.6      PPMV(WET)
T (DRY)       73.5      DEG.F,                   NO(ISO)     149.6      PPMV(WET)
T (WET)       69.3      DEG.F.                   O2           15.35     VOL.(DRY)
REL.HUM.      81.4      %                        CO2           3.82     VOL.(DRY)
ABS.HUM.       0.0145   LBS/LB                   CO            5.1      PPMV(DRY)
CDP          146.4      PSIA                     UHC           1.5      PPMV(WET)CH4
CDT          612.0      DEG.F.                   H2O           0.       GPM
I.G.V.        77.0      DEG.F.                   FUEL         10.832    PPS
COMP.EFF.     86.79  %                           WATER/FUEL    0.       LBS/LB
COMB.EFF.     99.90  %                           FBN           0.008    % BY WT.

                         FT.TEST          CHKD.          OXYGEN          CO2
                          FLOW            FLOW           CONC.           CONC.
WEX(DRY) MSCF/HR         25.8436         26.0124        26.0477         28.0818
WA           PPS        566.4           570.1          570.8           614.5
WA(ISO)      PPS        589.6           593.4          594.1           639.6

H2O   % OF COMP.          0.              0.             0.              0.
F/A                       0.0191          0.0190         0.0190          0.0176
NOX          PPH        435.1           432.8          438.4           471.4
NOX(ISO)     PPH        526.7           530.0          530.6           570.6
NOX   15% O2 DRY        177.2           178.4          178.6           191.9
NOX PPMBTU INPUT          0.57            0.57           0.57            0.61
NOX(ISO) PPMBTU           0.69            0.69           0.69            0.74
EI NOX PPTP FUEL         11.2            11.2           11.2            12.1
EI NOX(ISO)              13.5            13.6           13.6            14.6
ORG.NOX 100% YLD          3.1             3.1            3.1             2.8
O2 CONC %VOL.DRY         15.31           15.34          15.35           15.76
CO2     % VOL DRY         4.15            4.12           4.12            3.82
CO AT 15% O2 DRY          6.0             6.0            6.0             6.5
EI CO  PPTP FUEL          0.29            0.30           0.30            0.32
SO2      PPMV DRY        19.7            19.5           19.5            18.1
DRY TO WET    VOL          1.063           1.062          1.062           1.060
MMW(EXHAUST)             28.73           28.73          28.73           28.73
```

TABLE 18

MATERIALS AND PROCESSES LABORATORY
SCHENECTADY, NEW YORK
ANALYSIS REQUEST-REPORT

RECEIVED 5/24/78 LAB. NO. 78C-1068

REPORTED 5/31/78 SPECTRUM NO.

REQUESTED BY R.A. Hiskanin BLDG. 262 RM. 105 EXT.

PROJECT NO.

SHOP ORDER 531C-400-300-114 DEPT. CC.

DESCRIPTION OF MATERIAL Gas Turb. Lab
Fuel Type #2 (4-26) HLAP
SN 209

Analysis Requested	Wet	AA	X-Ray emiss	X-Ray diff	Spectro qual	Spectro quant	Probe	Organic	Thermal	Gas	Part. Study	Other
	☒	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☒

Wet: HHV, ash, N X-ray: S Evendale: H McBride: Spec. Grav. & Visc. @ 100°F
% water 210°F, C residue, Distillation curve,
Galbraith: C/H ratio aniline pt.

RESULTS	HHV (BTU/lb)	19,730
	ppm ash	32
	% N	0.008
	% S	0.11
	% H	13.55
	% H_2O	<0.02
	Sp. Gr. @ 100°F	0.820
	Sp. Gr. @ 210°F	0.782
	Viscosity @ 100°F	2.55
	Viscosity @ 210°	1.07
	Aniline Point °F	156
	Carbon Residue (10% Bottoms)	0.18

Distillation	°F		°F
Initial Point	326	50% Distilled	482
10% Distilled	396	60% "	502
20% "	422	70% "	526
30% "	440	80% "	550
40% "	464	90% "	576

Inquiries should be directed to: Dick Northrop/Bob McBride Ext. 5-2113

TABLE 18 CONCLUDED

RECEIVED 5/24/78 LAB. NO. 78C-1069

PORTED 5/31/78 SPECTRUM NO.

REQUESTED BY R.A. Miskanin BLDG. 262 RM. 165 EXT.

PROJECT NO.

SHOP ORDER 5H18-440-300-113 DEPT. CC.

DESCRIPTION OF MATERIAL Gas Turb. Lab

Fuel Type #2 (4-22) HLAP

SN 288

Analysis Requested	Wet	AA	X-Ray emiss	X-Ray diff	Spectro qual	Spectro quant	Probe	Organic	Thermal	Gas	Part. Study	Other
	☒	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☒

Wet: HHV, ash, H X-ray: S Evendale: N McBride: Spec. Grav. & Visc. @ 100°F

% water 210°F, C residue, Distillation curve.

Galbrath: C/H ratio aniline pt.

RESULTS	HHV (BTU/lb)	19,665
	ppm ash	23
	%N	0.009
	%S	0.11
	%H	13.40
	$\%H_2O$	<0.02
	Sp. Gr. @ 100°F	0.823
	Sp. Gr. @ 210°F	0.782
	Viscosity @ 100°F	2.59
	Viscosity @ 210°F	1.08
	Aniline Point	155°F
	Carbon Residue (10% bottoms)	0.29

Distillation	°F		°F
Initial Point	324	50% Distilled	487
10% Distilled	401	60% "	508
20% "	428	70% "	528
30% "	448	80% "	552
40% "	466	90% "	550

Inquiries should be directed to: Dick Northrup/Bob McBride Ext. 5-2113

TABLE 19

MATERIALS AND PROCESSES LABORATORY
SCHENECTADY, NEW YORK
ANALYSIS REQUEST-REPORT

RECEIVED 5/24/78 LAB. NO. 78C-1068

REPORTED 6/7/78 SPECTRUM NO. 8F1

REQUESTED BY R.A. Miskanin BLDG. 262 RM. 105 EXT.

PROJECT NO.

SHOP ORDER 5BT8-440-300-TT4 DEPT. CC.

DESCRIPTION OF MATERIAL Gas Turb. Lab

Fuel Type #2 (4-26) HL&P

SN 289

Analysis Requested	Wet	AA	X-Ray emiss	X-Ray diff	Spectro qual	Spectro quant	Probe	Organic	Thermal	Gas	Part. Study	Other
	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐	☒

Galbraith: C/H ratio

RESULTS approx. % in ash

Zn	major	>10
Pb		0.3
Sn		0.2
Si		0.2
Fe		0.2
Cu		0.1
Ca		0.04
Mg		0.02
V		0.01
Mo		0.01
Al		0.009
Ti		0.008
Mn		0.004
Ni		0.003
C		85.07
H		13.23

Inquiries should be directed to: BHKindt Ext. 5-2113

TABLE 19 CONCLUDED

RECEIVED 5/24/78

LAB. NO. 78C-1069

REPORTED 6/7/78

SPECTRUM NO. 8F1

REQUESTED BY H.A. Miskanin BLDG. 262 RM. 105 EXT.

PROJECT NO.

SHOP ORDER 5818-440-300-113 DEPT. CC.

DESCRIPTION OF MATERIAL Gas Turb. Lab
Fuel Type #2 (4-22) HL&P
SN 288

Analysis Requested	Wet	AA	X-Ray emiss	X-Ray diff	Spectro qual	Spectro quant	Probe	Organic	Thermal	Gas	Part. Study	Other
	☐	☐	☐	☐	☒	☐	☐	☐	☐	☐	☐	☒

Galbraith: C/H ratio

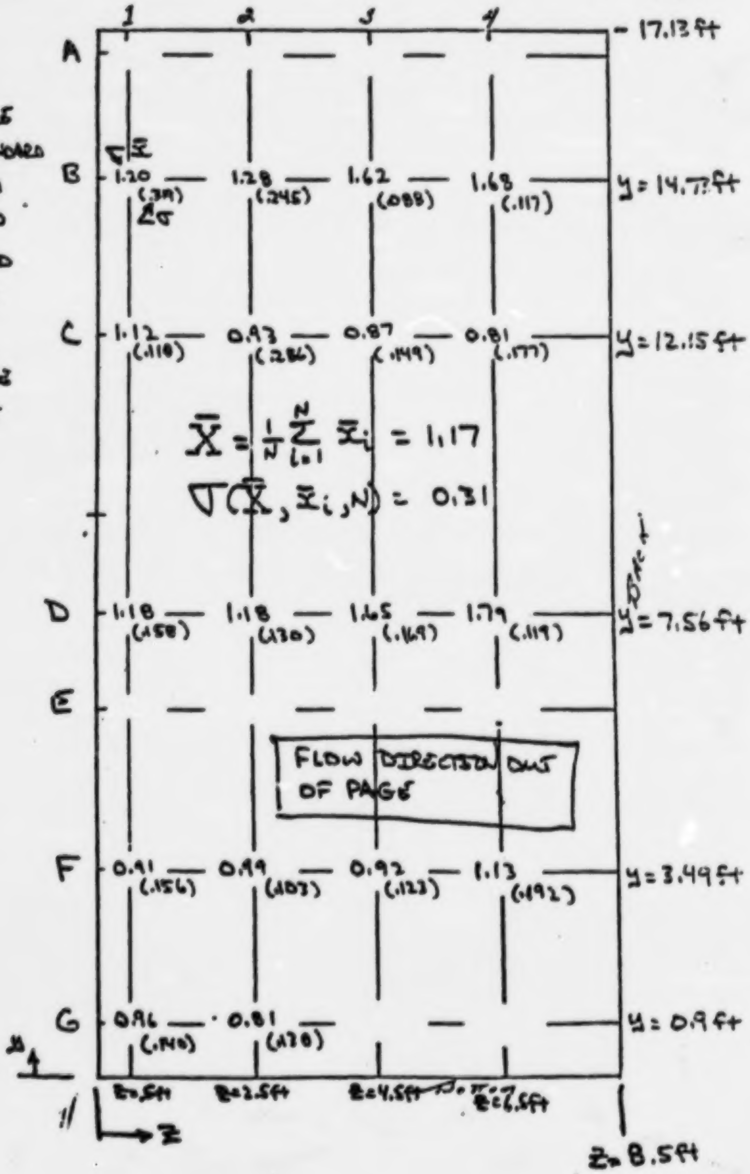
RESULTS approx. % in ash

Zn	major	>10
Pb		0.2
Fe		0.2
Sn		0.1
Cu		0.1
V		0.05
Si		0.04
Ca		0.03
Ni		0.02
Mg		0.01
Mo		0.006
Al		0.005
Mn		0.002
C		84.83
H		13.07

Inquiries should be directed to: B H Kilt Ext. 5-2113

DATA PRESENTED ARE MEANS ($\bar{x}$) AND STANDARD DEVIATIONS AT EACH SAMPLE POINT, AND THE MEAN ($\bar{X}$) AND DEVIATION FOR THE ENTIRE STACK.

ALL QUANTITIES ARE IN PPM BY VOLUME

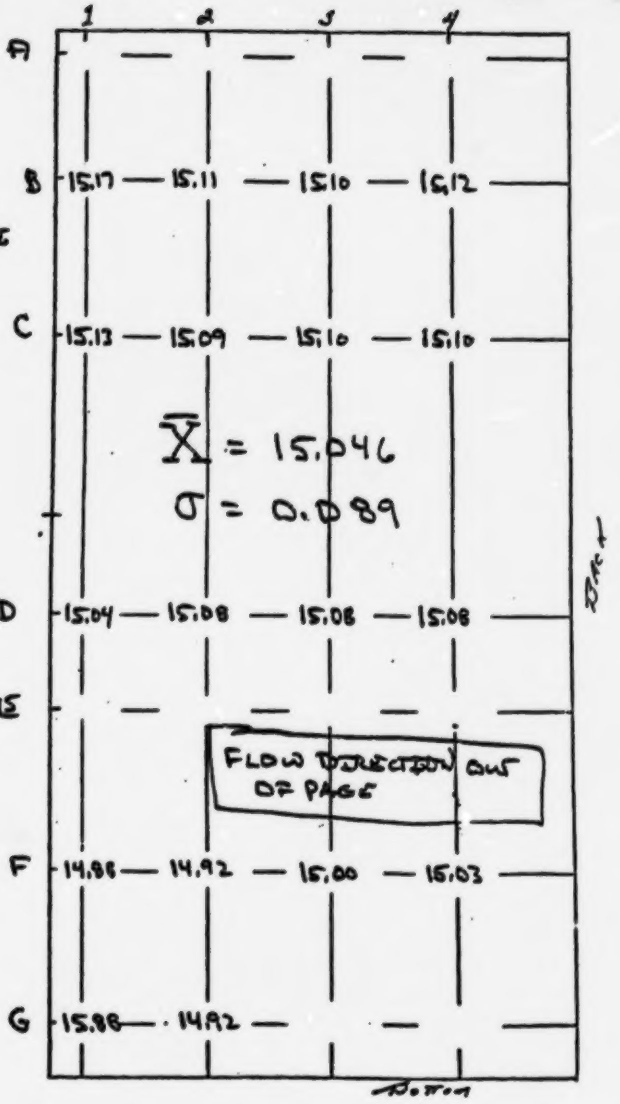

1
2
3
4
A
B
C
D
E
F
G
- 17.13 ft
y = 14.77 ft
y = 12.15 ft
y = 7.56 ft
y = 3.49 ft
y = 0.9 ft
σ
$\bar{x}$
1.20 (.39)
1.28 (.245)
1.62 (.088)
1.68 (.117)
1.12 (.118)
0.93 (.286)
0.87 (.149)
0.81 (.177)
1.18 (.158)
1.18 (.130)
1.65 (.169)
1.79 (.119)
0.91 (.156)
0.99 (.103)
0.92 (.123)
1.13 (.192)
0.96 (.140)
0.81 (.130)
FLOW DIRECTION OUT OF PAGE
Stack
y
z
z = .5 ft
z = 2.5 ft
z = 4.5 ft
z = 6.5 ft
z = 8.5 ft

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} \bar{x}_i = 1.17$$

$$\sigma(\bar{X}, \bar{x}_i, N) = 0.31$$

Figure 1. M5700IC total hydrocarbon emissions at base load with water injection.

DATA ARE MEAN READINGS AT EACH SAMPLE POINT. STANDARD DEVIATIONS FOR THESE READINGS ARE LESS THAN 0.01.


FLOW DIRECTION OUT OF PAGE
Back
Bottom

	1	2	3	4
A				
B	15.17	15.11	15.10	15.12
C	15.13	15.09	15.10	15.10
D	15.04	15.08	15.08	15.08
E				
F	14.88	14.92	15.00	15.03
G	15.88	14.92		

$\bar{X} = 15.046$

$\sigma = 0.089$

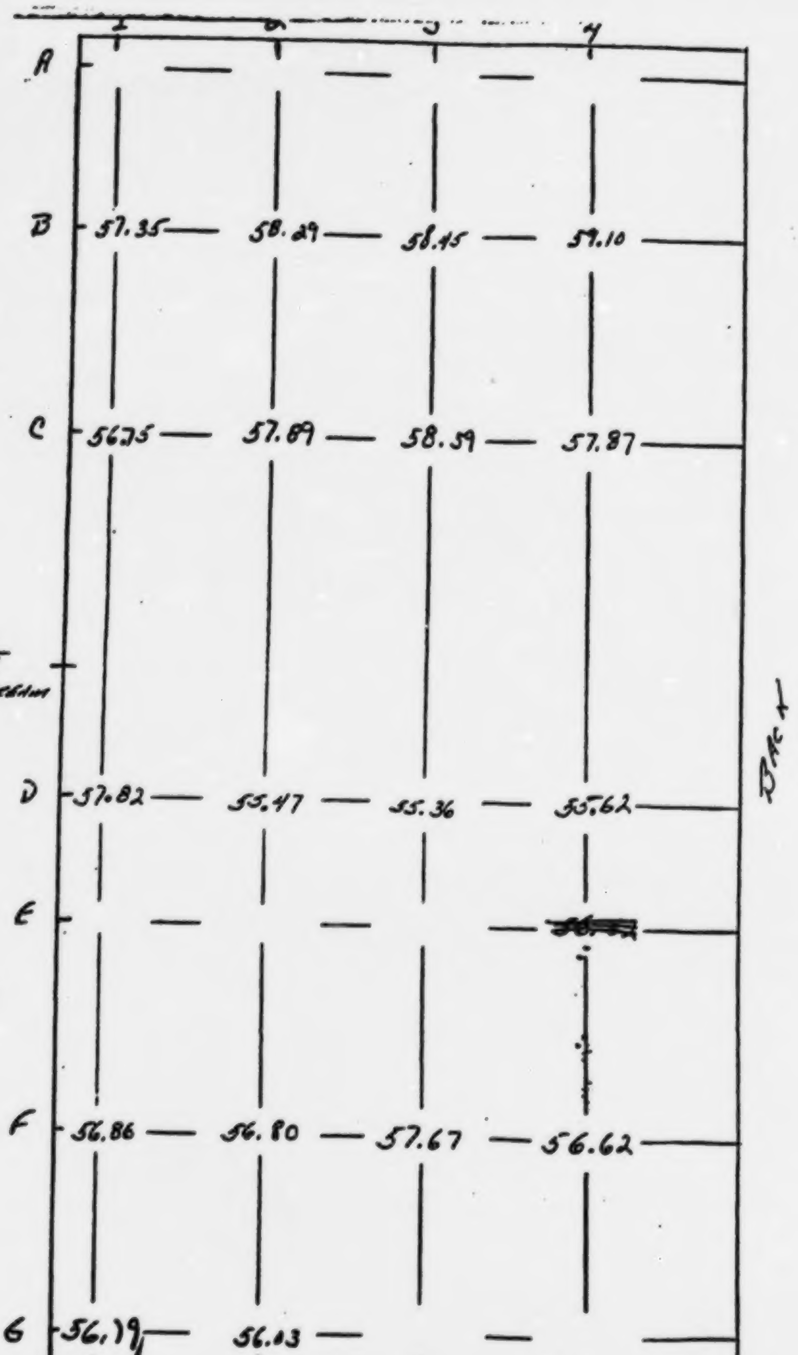
Figure 2. M57001C oxygen concentration in exhaust at base load with water injection.

FACING AGAINST AIR FLOW

NOx DATA
No A/Eas.
PPMV

THIS PORT ≈ 40" UP STREAM

$\bar{x} = 57.19$
$\sigma = 1.113$
$\frac{\sigma}{\bar{x}} = .0195$
Base
40 Gpm
H2O Inj



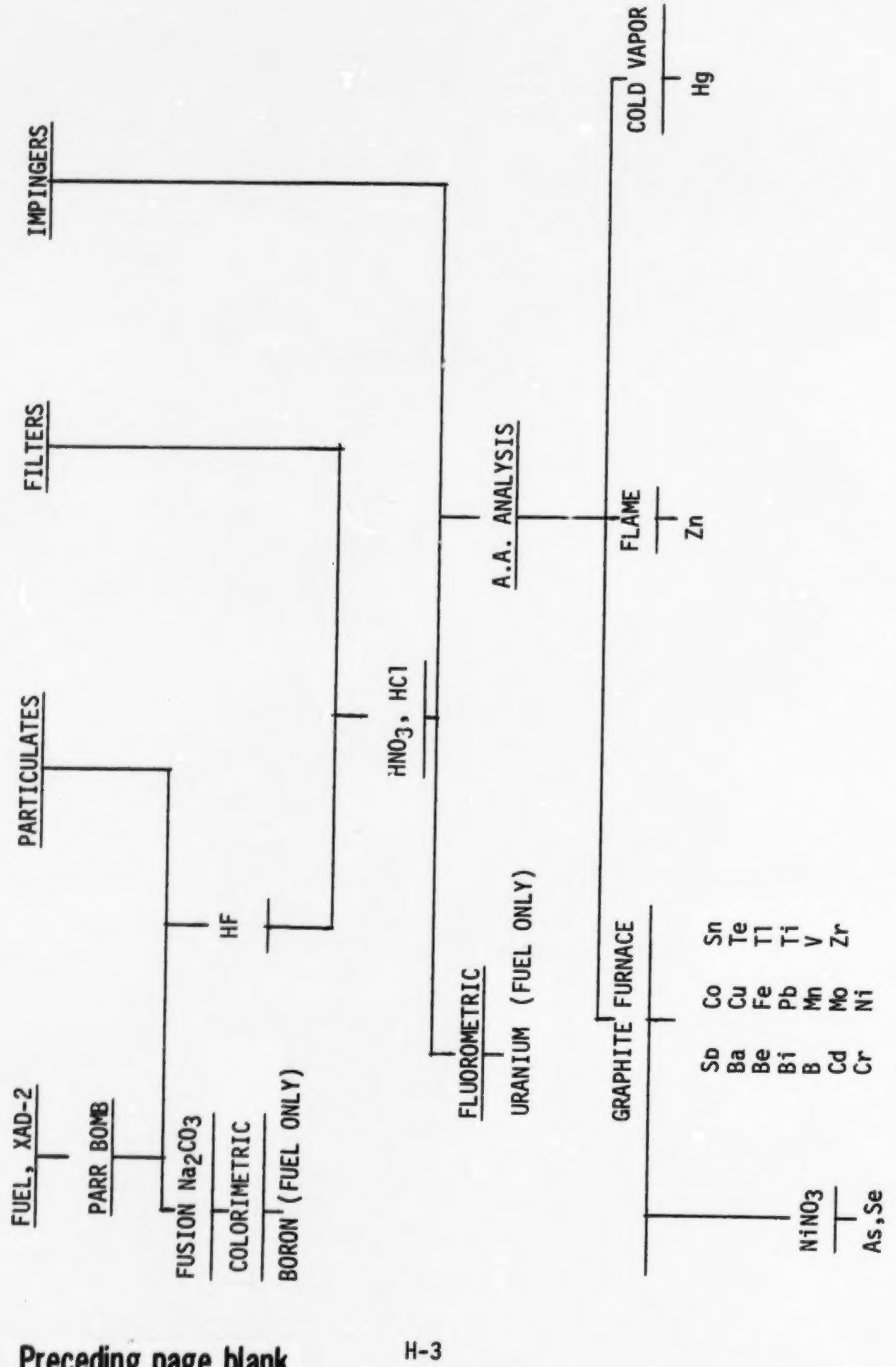
	1	2	3	4
A				
B	57.35	58.29	58.45	59.10
C	56.75	57.89	58.59	57.87
D	57.82	55.47	55.36	55.62
E				~~[illegible]~~
F	56.86	56.80	57.67	56.62
G	56.19	56.03		

Figure 3.

APPENDIX H

ANALYTICAL PROCEDURES

ELEMENTAL ANALYSIS FLOWSHEET


FUEL, XAD-2
PARR BOMB
FUSION Na2CO3
COLORIMETRIC
BORON (FUEL ONLY)
PARTICULATES
HF
FILTERS
IMPINGERS
HNO3, HCl
FLUOROMETRIC
URANIUM (FUEL ONLY)
A.A. ANALYSIS
GRAPHITE FURNACE
Sb Ba Be Bi B Cd Cr
Co Cu Fe Pb Mn Mo Ni
Sn Te Tl Ti V Zr
NiNO3
As,Se
FLAME
Zn
COLD VAPOR
Hg

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APPENDIX I

BIOASSAY RESULTS

LBI ASSAY NO. 3986

LBI SAFETY NO. 3643

MUTAGENICITY EVALUATION OF

OIL FIRED GAS TURBINE NO. 1 SASS TRAIN XAD-2 EXTRACT (IN METHYLENE CHLORIDE)

IN THE AMES SALMONELLA/MICROSOME PLATE TEST

FINAL REPORT

SUBMITTED TO:

ACUREX CORPORATION
485 CLYDE AVENUE
MOUNTAIN VIEW, CA.
94042

SUBMITTED BY:

LITTON BIONETICS, INC.
5516 NICHOLSON LANE
KENSINGTON, MARYLAND 20795

LBI PROJECT NO. 20988

REPORT DATE: JUNE 1979

Litton BIONETICS

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PREFACE

This report contains a summary of the data compiled during the evaluation of the test compound. The report is organized to present the results in a concise and easily interpretable manner. The first part contains items I-IX. Items I-IV provide sponsor and compound identification information, type of assay, and the protocol reference number. All protocol references indicate a standard procedure described in the Litton Bionetics, Inc. "Screening Program for the Identification of Potential Mutagens and Carcinogens." Item V provides the initiation and completion dates for the study, and Item VI provides identification of supervisory personnel. Item VII identifies the tables and/or figures containing the data used by the study director in interpreting the test results. The interpretation itself is in Item VIII. Item IX provides the conclusion and evaluation.

The second part of the report, entitled PROTOCOL, describes the materials and procedures employed in conducting the assay. This part of the report also contains evaluation criteria used by the study director, and any appendices. The evaluation criteria are included to acquaint the sponsor with the methods used to develop and analyze the test results.

All test and control results presented in this report are supported by fully documented raw data which are permanently maintained in the files of the Department of Genetics and Cell Biology or in the archives of Litton Bionetics, Inc., 5516 Nicholson Lane, Kensington Maryland, 20795.

I. SPONSOR: Acurex Corporation

II. MATERIAL (TEST COMPOUND): LBI ASSAY NUMBER 3986

A. Identification: Oil Fired Gas Turbine No. 1 Sass Train XAD-2 Extract (in Methylene Chloride)*

B. Date Received: February 23, 1979

C. Physical Description: Clear yellow liquid

III. TYPE OF ASSAY: Ames *Salmonella*/microsome Mutagenesis Assay

IV. PROTOCOL NUMBER: 401

V. STUDY DATES:

A. Initiation: May 18, 1979

B. Completion: June 8, 1979

VI. SUPERVISORY PERSONNEL:

A. Study Director: D.R. Jagannath, Ph.D.

B. Laboratory Supervisor: Sibyl Goode

VII. RESULTS:

The results of this assay are presented in Tables 1 and 2.

VIII. INTERPRETATION OF RESULTS:

The test compound was examined for mutagenic activity in a series of *in vitro* microbial assays employing *Salmonella* indicator organisms. The compound was tested directly and in the presence of liver microsomal enzyme preparations from Aroclor-induced rats.

The compound was tested at four concentrations according to the IERL-RTP procedures Manual: Level I (1977). The compound was tested for its mutagenic activity as well as for its toxicity at 0.01 mg, 0.1 mg, 1.0 mg and 10 mg per plate.

The toxicity results presented in Table 1 indicate that the test compound was not toxic at the doses employed in these studies both in the presence and absence of metabolic activation systems.

*See Sample Preparation and Handling.

VIII. INTERPRETATION OF RESULTS (continued):

The mutagenicity results presented in Table 2 indicate that the test compound did not induce any genetic activity in any of the test organisms employed in these assays. The results of tests conducted on the test compound in the presence of a rat liver activation system were also negative. The test with TA-1537 was repeated in nonactivation and activation assays because of high solvent values in the initial test. The repeat tests were also negative.

IX. CONCLUSIONS:

The test compound, Oil Fired Gas Turbine No. 1 Sass train XAD-2 extract (in methylene chloride) did not demonstrate genetic activity or toxicity in any of the assays conducted in this evaluation and was considered as not mutagenic under these test conditions.

Submitted by:

Study Director

D.R. Jagannath 6.11.79

D.R. Jagannath, Ph.D. Date
Section Chief
Submammalian Genetics
Department of Genetics
and Cell Biology

Reviewed by:

(for) 6/11/79

David J. Brusick, Ph.D. Date
Director
Department of Genetics
and Cell Biology

Litton BIONETICS

V. RESULTS

TABLE I

A. NAME OR CODE DESIGNATION OF THE TEST COMPOUND: OIL FIRED GAS TURBINE NO1 SASS TRAIN XAD-2 EXTRACT (IN METHYLENE CHLORIDE)
B. SOLVENT: DMSO
C. TEST INITIATION DATES: 05/18/79 05/30/79
D. TEST COMPLETION DATE:06/08/79
E. S-9 LOT#: CH024
NOTE: CONCENTRATIONS ARE GIVEN IN MILLIGRAMS (MG) PER PLATE.

TEST	SPECIES	TISSUE	INDICATOR ORGANISMS (POPULATION/10^6)							
			TA-1535		TA-1537		TA-98		TA-100	
			1	2	1	2	1	2	1	2
NONACTIVATION										
SOLVENT CONTROL	---	---	393		264	167	298		1853	
POSITIVE CONTROL**	---	---	315		159	91	298		1649	
TEST COMPOUND										
0.010000 MG	---	---	341		280	153	221		440	
0.100000 MG	---	---	362		244	194	280		391	
1.000000 MG	---	---	346		282	125	305		353	
10.000000 MG	---	---	326		267	177	354		353	
ACTIVATION										
SOLVENT CONTROL	RAT	LIVER	378		311	149	351		400	
POSITIVE CONTROL***	RAT	LIVER	551		191	101	312		331	
TEST COMPOUND										
0.010000 MG	RAT	LIVER	437		285	153	388		389	
0.100000 MG	RAT	LIVER	380		299	158	341		348	
1.000000 MG	RAT	LIVER	383		297	186	402		350	
10.000000 MG	RAT	LIVER	196		270	168	378		346	

**

TA-1535	SODIUM AZIDE	1 UG/PLATE
TA-1537	9-AMINOACRIDINE	50 UG/PLATE
TA-98	2-NITROFLUORENE	10 UG/PLATE
TA-100	SODIUM AZIDE	1 UG/PLATE
SOLVENT	50 UL/PLATE	

***

TA-1535	2-ANTHRAMINE	2.5 UG/PLATE
TA-1537	2-ANTHRAMINE	2.5 UG/PLATE
TA-98	2-ANTHRAMINE	2.5 UG/PLATE
TA-100	2-ANTHRAMINE	2.5 UG/PLATE

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V. RESULTS

TABLE 2

A. NAME OR CODE DESIGNATION OF THE TEST COMPOUND: OIL FIRED GAS TURBINE NO1 SASS TRAIN XAD-2 EXTRACT (IN METHYLENE CHLORIDE)
B. SOLVENT: DMSO
C. TEST INITIATION DATES: 05/18/79
D. TEST COMPLETION DATE: 06/08/79
E. S-9 LOT#:
NOTE: CONCENTRATIONS ARE GIVEN IN MILLIGRAMS (MG) PER PLATE

TEST	SPECIES	TISSUE	INDICATOR ORGANISMS (REVERTANTS/PLATE)							
			TA-1535		TA-1537		TA-98		TA-100	
			1	2	1	2	1	2	1	2
NONACTIVATION										
SOLVENT CONTROL	---	---	20		45	11	55		124	
POSITIVE CONTROL**	---	---	1023		352	265	1384		1923	
TEST COMPOUND										
0.010000 MG	---	---	20		41	6	46		140	
0.100000 MG	---	---	10		34	8	45		106	
1.000000 MG	---	---	21		25	7	42		110	
10.000000 MG	---	---	11		25	5	68		108	
ACTIVATION										
SOLVENT CONTROL	RAT	LIVER	16		52	11	65		112	
POSITIVE CONTROL***	RAT	LIVER	414		272	110	2926		2046	
TEST COMPOUND										
0.010000 MG	RAT	LIVER	14		43	15	58		91	
0.100000 MG	RAT	LIVER	7		53	13	75		100	
1.000000 MG	RAT	LIVER	13		C	7	55		89	
10.000000 MG	RAT	LIVER	16		42	8	63		109	

**

TA-1535	SODIUM AZIDE	1 UG/PLATE
TA-1537	9-AMINOACRIDINE	50 UG/PLATE
TA-98	2-NITROFLUORENE	10 UG/PLATE
TA-100	SODIUM AZIDE	1 UG/PLATE
SOLVENT	50 UL/PLATE	

***

TA-1535	2-ANTHRAMINE	2.5 UG/PLATE
TA-1537	2-ANTHRAMINE	2.5 UG/PLATE
TA-98	2-ANTHRAMINE	2.5 UG/PLATE
TA-100	2-ANTHRAMINE	2.5 UG/PLATE

C INDICATES CONTAMINATION

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SAMPLE PREPARATION AND HANDLING

The test material was received as a solution in 1.2 ml of methylene chloride and was stored at 4°C until solvent exchanged. The entire sample was exchanged into DMSO by first adding 2 ml DMSO and reducing the volume to 2 ml under a stream of nitrogen in a warm water bath (33°C). Then 0.5 ml DMSO was added and the solution evaporated again to 2 ml. This last process was repeated once more, leaving the sample in a final volume of 2.0 ml. This sample was stored at 4°C until use in the cytotoxicity assay. Since the original test sample represented 307 ft^3 of exhaust gas, the solvent exchanged sample corresponded to 153.5 ft^3 gas/ml or 4346.5 L gas/ml.

A solvent exchanged DMSO blank was also prepared by the above procedure, starting with 1.2 ml methylene chloride (same volume as the original test material). Since the test material did not exhibit any mutagenic or toxic effect on the indicator organism in these assays, solvent exchanged DMSO blank was not tested separately.

PROTOCOL NO. 401

AMES SALMONELLA/MICROSOME PLATE ASSAY

1. OBJECTIVE

The objective of this study is to evaluate a test material for mutagenic activity in a bacterial assay with and without a mammalian S9 activation system.

2. RATIONALE

The Salmonella typhimurium strains used at LBI are all histidine auxotrophs by virtue of mutations in the histidine operon. When these histidine-dependent cells are grown in a minimal media petri plate containing a trace of histidine, only those cells that revert to histidine independence (his+) are able to form colonies. The trace amount of histidine allows all the plated bacteria to undergo a few divisions; this growth is essential for mutagenesis to occur. The his+ revertants are easily scored as colonies against the slight background growth. The spontaneous mutation frequency of each strain is relatively constant; but when a mutagen is added to the agar, the mutation frequency is increased 2- to 100-fold. Cells which grow to form colonies on the minimal media petri plates are therefore assumed to have reverted, either spontaneously or by the action of a test substance to his+ genotype.

3. MATERIALS

A. Indicator Microorganisms

The Salmonella typhimurium strains used in this assay were obtained from Dr. Bruce Ames, University of California at Berkeley.[1-3] The following 5 strains are routinely used.

Strain Designation	Gene Affected	Additional Mutations			Mutation Type Detected
		Repair	LPS	R Factor	
TA-1535	his G	Δ uvr B	rfa	-	Base-pair substitution
TA-1537	his C	Δ uvr B	rfa	-	Frameshift
TA-98	His D	Δ uvr B	rfa	pKM101	Frameshift
TA-100	his G	Δ uvr B	rfa	pKM101	Base-pair substitution

All the above strains have, mutation in the histidine operon, mutation (rfa$^-$) that leads to defective lipopolysaccharide coat, a deletion that covers genes involved in the synthesis of vitamin biotin (bio$^-$) and in the repair of ultraviolet (uv) - induced DNA damage (uvrB$^-$). The rfa$^-$ mutation makes the strains more permeable to many large molecules. The uvrB$^-$ mutation decreases repair of some types of chemically or physically damaged DNA and thereby enhances the strain's sensitivity to some mutagenic agents. The resistant transfer factor plasmid (R factor) pKM101, in TA-98 and TA-100 is believed to cause an increase in error-prone DNA repair that leads to many more mutations for a given dose of most mutagens[3]. In addition, plasmid pKM101 confers resistance to the antibiotic ampicillin, which is a convenient marker to detect the presence of plasmid in the cells.

All indicator strains are kept at 4°C on minimal medium plates supplemented with a trace of biotin and an excess of histidine. The plates with plasmid-carrying strains contain in addition ampicillin (25 µg/ml), to ensure stable maintenance of plasmid pKM101. New stock culture plates are made every two months from the frozen master cultures or from single colony reisolates that were checked for their genotypic characteristics (his, rfa, uvrB, bio) and for the presence of plasmid. For each experiment, an inoculum from the stock culture plates is grown overnight at 37°C in nutrient broth (Oxoid CM67) and used.

B. Media

The bacterial strains were cultured in Oxoid Media #2 (nutrient Broth). The selective medium was Vogel Bonner Medium E with 2% glucose. The overlay agar will consist of 0.6% purified agar with 0.5 mM histidine, 0.05 mM biotin and 0.1M NaCl according to the methods of Ames et al.[4]

C. Activation System

(1) S9 Homogenate

A 9,000 x g supernatant prepared from Sprague-Dawley adult male rat liver induced by Aroclor 1254 (described by Ames et al.[5]) was purchased from Bionetics Laboratory Products, Litton Bionetics, Inc. and used in this assay.

(2) S9 Mix

Components	Concentration per Milliliter S9 Mix
NADP (sodium salt	4 µmoles
D-glucose-6-phosphate	5 µmoles
$MgCl_2$	8 µmoles
KCl	33 µmoles
Sodium phosphate buffer pH 7.4	100 µmoles
Organ homogenate from rat liver (S9 fraction)	100 µliters

4. EXPERIMENTAL DESIGN

A. Dosage Selection

The tests are run at four concentrations according to the EPA Level I Manual. The recommended doses are 0.01, 0.1, 1.0 and 10 mg per plate. Both mutagenicity testing and toxicity testing are performed using these four doses.

B. Mutagenicity Testing

The procedure used is based on the paper published by Ames *et al.*[6] and is performed as follows:

(1) Nonactivation Assay

To a Sterile 13 x 100 mm test tube placed in a 43°C water bath the following is added in order:

(a) 2.00 ml of 0.6% agar containing 0.05 mM histidine and 0.05 mM biotin.

(b) 0.05 ml of a solution of the test chemical to give approximate dose.

(c) 0.1 ml - 0.2 ml of indicator organism/s.

(d) 0.50 ml of 0.01M phosphate buffer, pH 7.4.

This mixture is swirled gently and then poured into minimal agar plates (see 3B, Media). After the top agar has set, the plates are incubated at 37°C for approximately 2 days. The number of his+ revertant colonies growing in the plates is counted and recorded.

(2) Activation Assay

The activation assay is run concurrently with the nonactivation assay. The only difference is the addition of 0.5 ml of S9 mix (see 3C:2, Activation System) to the tubes in place of 0.5 ml of phosphate buffer which is added in nonactivation assays. All other details are similar to the procedure for nonactivation assays.

A detailed flow diagram for the plate incorporation assay is provided in Figure 1.

C. Control Compounds

A negative control consisting of the solvent used for the test material is performed in all cases. For negative controls, step 'b' of Nonactivation Assays is replaced by 0.05 ml of the solvent. The negative controls are employed for each indicator strain and is performed in the absence and presence of S9 mix. The solvent used to prepare the stock solution of the test material is given in the Results section of this report. All dilutions of the test material made using this solvent.

Specific positive control compounds known to revert each strain are also used in the assays. The concentrations and specificities of these compounds to specific strains are given in the following table.

Assay	Chemical	Solvent	Concentration per Plate (μg)	Salmonella Strains
Nonactivation	Sodium azide	Water	1	TA-1535, TA-100
	2-Nitrofluorene (NF)	Dimethylsulfoxide	10	
	9-aminoacridine (9AA)	Ethanol	50	TA-1537
Activation	2-anthramine (ANTH)	Dimethylsulfoxide	2.5	For all strains

D. Toxicity Test

To a sterile 13 x 100 mm test tube placed in a 43°C water bath the following is added in order:

(a) 2.0 ml of 0.6% agar containing 0.05 mM histidine and 0.05 mM biotin.

(b) 0.05 ml of a solution of the test chemical to give approximate dose.

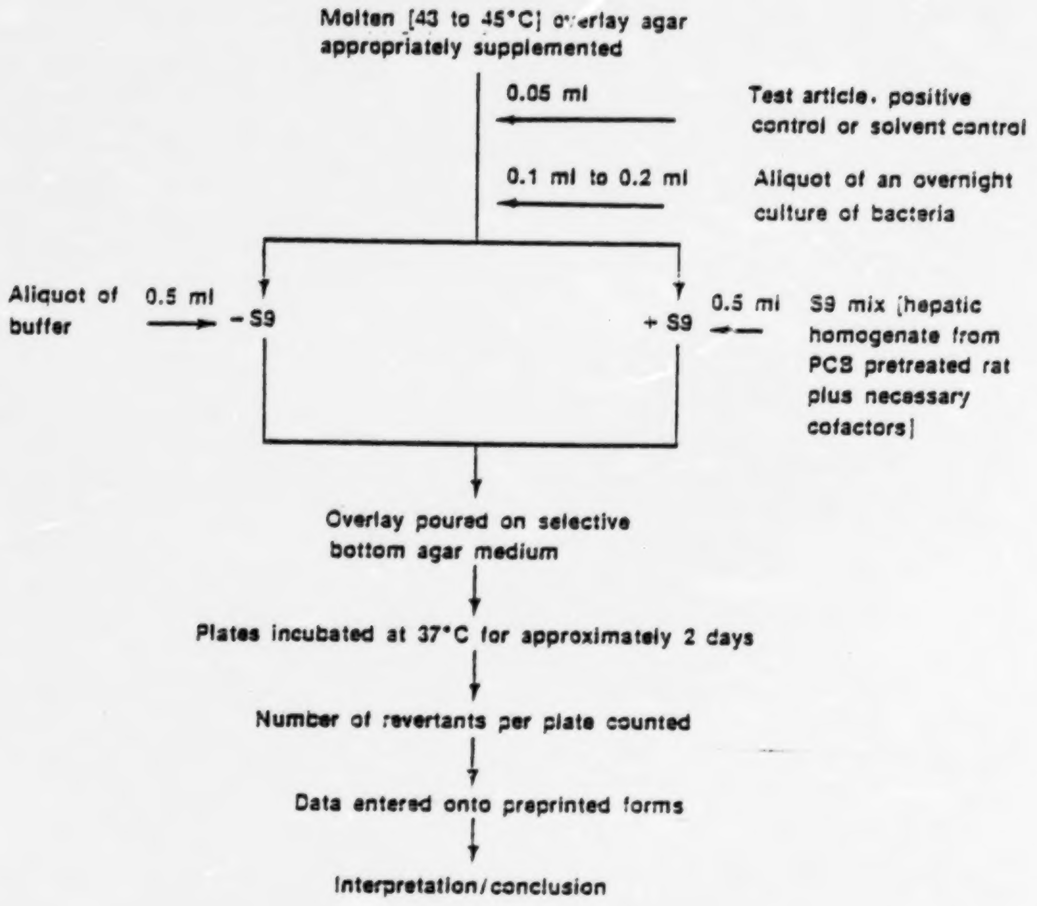
(c) 0.1-0.2 ml of indicator cells (approximately 200 cells from an overnight culture appropriately dilute)

(d) 0.50 ml of 0.01M phosphate buffer, pH 7.4 (for nonactivation assays) or S9 mix (see 3c:2) (for activation assays)

This mixture is swirled gently and then poured over the surface of nutrient agar plates. After the top agar has set, the plates are incubated at 37°C for 2 days. The number of colonies growing on the plates is counted and recorded.

FIGURE 1

REVERSE MUTATION ASSAY
[Agar Incorporation Method]


Molten [43 to 45°C] overlay agar appropriately supplemented
0.05 ml
Test article, positive control or solvent control
0.1 ml to 0.2 ml
Aliquot of an overnight culture of bacteria
Aliquot of buffer
0.5 ml
- S9
+ S9
0.5 ml
S9 mix [hepatic homogenate from PCB pretreated rat plus necessary cofactors]
Overlay poured on selective bottom agar medium
Plates incubated at 37°C for approximately 2 days
Number of revertants per plate counted
Data entered onto preprinted forms
Interpretation/conclusion

5. EVALUATION CRITERIA

Statistical methods are not currently used, and evaluation is based on the criteria included in this protocol.

Plate test data consists of direct revertant colony counts obtained from a set of selective agar plates seeded with populations of mutant cells suspended in a semisolid overlay. Because the test material and the cells are incubated in the overlay for approximately 2 days and a few cell divisions occur during the incubation period, the test is semiquantitative in nature. Although these features of the assay reduce the quantitation of results, they provide certain advantages not contained in a quantitative suspension test:

- The small number of cell divisions permits potential mutagens to act on replication DNA, which is often more sensitive than nonreplicating DNA.
- The combined incubation of the test article and the cells in the overlay permits constant exposure of the indicator cells for approximately 2 days.

A. Surviving Populations

Plate test procedures do not permit exact quantitation of the number of cells surviving chemical treatment. At low concentrations of the test material, the surviving population on the treatment plates is essentially the same as that on the negative control plate. At high concentrations, the surviving population is usually reduced by some fraction. Our protocol will normally employ several doses ranging over two or three log concentrations, the highest of these doses being selected to show slight toxicity as determined by subjective criteria.

B. Dose-Response Phenomena

The demonstration of dose-related increases in mutant counts is an important criterion in establishing mutagenicity. A factor that might modify dose-response results for a mutagen would be the selection of doses that are too low (usually mutagenicity and toxicity are related). If the highest dose is far lower than a toxic concentration, no increases may be observed over the dose range selected. Conversely, if the lowest dose employed is highly cytotoxic, the test material may kill any mutants that are induced, and the test material will not appear to be mutagenic.

C. Control Tests

Positive and negative control assays will be conducted with each experiment and will consist of direct-acting mutagens for nonactivation assays and mutagens that require metabolic biotransformation in activation assays. Negative controls will consist of the test material solvent in the overlay agar together with the other essential components. The negative control plate for each strain will give a reference point to which the test data will be compared. The positive control assay will be conducted to demonstrate that the test systems are functional with known mutagens.

D. Evaluation Criteria for Ames Assay

Because the procedures to be used to evaluate the mutagenicity of the test material are semiquantitative, the criteria to be used to determine positive effects are inherently subjective and are based primarily on a historical data base. Most data sets will be evaluated using the following criteria.

(1) Strains TA-1535, TA-1537

If the solvent control value is within the normal range, a test material that produces a positive dose response over three concentrations with the highest increase equal to three times the solvent control value will be considered to be mutagenic.

(2) Strains TA-98 and TA-100

If the solvent control value is within the normal range, a test material that produces a positive dose response over three concentrations with the highest increase equal to twice the solvent control value for TA-98 and TA-100 will be considered to be mutagenic.

(3) Pattern

Because TA-1535 and TA-100 are both derived from the same parental strain (G-46) and because TA-1538 and TA-98 are both derived from the same parental strain (D3052), to some extent there is a built-in redundancy in the microbial assay. In general, the two strains of a set respond to the same mutagen and such a pattern is sought. Generally, if a strain responds to a mutagen in nonactivation tests, it will do so in activation tests.

(4) Reproducibility

If a test material produces a response in a single test that cannot be reproduced in additional runs, the initial positive test data lose significance.

The preceding criteria are not absolute, and other extenuating factors may enter into a final evaluation decision. However, these criteria will be applied to the majority of situations and are presented to aid those individuals not familiar with this procedure. As the data base is increased, the criteria for evaluation can be more firmly established.

E. Relation between Mutagenicity and Carcinogenicity

It must be emphasized that the Ames *Salmonella*/Microsome Plate Assay is not a definitive test for chemical carcinogens. It is recognized, however, that correlative and functional relations have been demonstrated between these two endpoints. The results of comparative tests on 300 chemicals by McCann *et al.*[1] show an extremely good correlation between results of microbial mutagenesis tests and *in vivo* rodent carcinogenesis assays.

All evaluations and interpretation of the data to be presented in the final report will be based only on the demonstration, or lack, of mutagenic activity.

REFERENCES

1. J. McCann, E. Choi, E. Yamasaki, and B.N. Ames. Detection of carcinogens as mutagens in the *Salmonella*/microsome test: Assay of 300 chemicals. Proc. Nat. Acad. Sci. USA 72, 5135-5139 (1975).

2. B.N. Ames, E.G. Gurney, J.A. Miller, and H. Bartsch. Carcinogens as frameshift mutagens: Metabolites and derivatives of 2-acetylaminofluorene and other aromatic amine carcinogens. Proc. Nat. Acad. Sci. USA 69, 3128-3132 (1972).

3. B.N. Ames, F.D. Lee, and W.E. Durston. An improved bacterial test system for the detection and classification of mutagens and carcinogens. Proc. Nat. Acad. Sci. USD 70, 782-786 (1973).

4. B.N. Ames, W.E. Durston, E. Yamasaki, and F.D. Lee. Carcinogens are mutagens: A simple test system combining liver homogenates for activation and bacteria for detection. Proc. Nat. Acad. Sci. USA 70, 2231-2285 (1973).

5. J. McCann, N.E. Springarn, J. Kobori, and B.N. Ames. Detection of carcinogens as mutagens: Bacterial tester strains with R factor plasmids. Proc. Nat. Acad. Sci. USA 72, 979-983 (1975).

6. B.N. Ames, J. McCann, and E. Yamasaki. Methods for detecting carcinogens and mutagens with the *Salmonella*/mamallian-microsome mutagenicity test. Mutation Res. 31, 347-364 (1975).

7. H.J. Vogel and D.M. Bonner. Acetylornithinase of *E. coli* partial purification and some properties. J. Biol. Chem., 218, 97-106 (1956).

LBI ASSAY NO. 3986

LBI SAFETY NO. 3643

CYTOTOXIC EVALUATION OF

OIL FIRED GAS TURBINE NO. 1
SASS TRAIN XAD-2 EXTRACT

IN THE
WI-38 HUMAN CELL CYTOTOXICITY ASSAY

FINAL REPORT

SUBMITTED TO:

ACUREX CORPORATION
485 CLYDE AVE.
MOUNTAIN VIEW, CA 94042

SUBMITTED BY:

LITTON BIONETICS, INC.
5516 NICHOLSON LANE
KENSINGTON, MARYLAND 20795

LBI PROJECT NO. 20993

REPORT DATE: JUNE, 1979

Litton BIONETICS

PREFACE

This report contains a summary of the data compiled during the evaluation of the test compound. The report is organized to present the results in a concise and easily interpretable manner. The first part contains items I-IX. Items I-IV provide sponsor and compound identification information, type of assay, and the protocol reference number. All protocol references indicate a standard procedure described in the Litton Bionetics, Inc. "Screening Program for the Identification of Potential Mutagens and Carcinogens." Item V provides the initiation and completion dates for the study, and Item VI provides identification of supervisory personnel. Item VII identifies the tables and figures containing the data used by the study director in interpreting the test results. The interpretation itself is in Item VIII. Item IX provides the conclusion and evaluation.

The second part of the report, entitled PROTOCOL, describes the materials and procedures employed in conducting the assay. This part of the report also contains evaluation criteria used by the study director, and any appendices. The evaluation criteria are included to acquaint the sponsor with the methods used to develop and analyze the test results.

All test and control results presented in this report are supported by fully documented raw data which are permanently maintained in the files of the Department of Genetics and Cell Biology or in the archives of Litton Bionetics, Inc., 5516 Nicholson Lane, Kensington Maryland, 20795.

Copies of raw data will be supplied to the sponsor upon request.

I. SPONSOR: ACUREX CORPORATION

II. MATERIAL (TEST COMPOUND): LBI ASSAY NUMBER 3986

A. Identification: Oil Fired Gas Turbine No. 1, SASS Train XAD-2 Extract

B. Date Received: February 23, 1979

C. Physical Description: Light yellow solution in DMSO

III. TYPE OF ASSAY: WI-38 Human Cell Cytotoxicity Assay

IV. PROTOCOL NUMBER: Special Protocol

V. STUDY DATES:

A. Initiation: May 29, 1979

B. Completion: June 5, 1979

VI. SUPERVISORY PERSONNEL:

A. Study Director: Brian C. Myhr, Ph.D.

B. Laboratory Supervisor: Robert Young

VII. RESULTS:

The data are presented in Table 1 on page 3 and in Figures 1 and 2 on pages 4 and 5.

VIII. INTERPRETATION OF RESULTS:

The methylene chloride extract of the test sample on XAD-2 resin, after solvent exchange into DMSO, appeared to remain soluble in the culture medium at the highest assayed concentration of 20 µl/ml. Higher concentrations could not be tested because of the introduction of greater than 2% organic solvent by volume. As shown in Table 1, 1% DMSO reduced the viability index, total protein, and total ATP to about 70-80% of the untreated negative control; 2% DMSO reduced these parameters even further to about 40-65%. The corresponding concentrations of solvent exchanged DMSO were somewhat less toxic to these assay parameters, showing that residual methylene chloride does not contribute to the solvent toxicity. Because of the solvent toxicity, the effect of the test material was measured relative to the assay parameters obtained for the appropriate solvent exchanged DMSO negative control.

VIII. INTERPRETATION OF RESULTS (continued):

The most responsive assay parameter appeared to be the viability index, although the protein and ATP contents started to decrease similarly at the highest dose of 20 µl/ml. The percent viability and ATP per 10^6 cells parameters gave no indication of any toxicity. A 50% reduction was not achieved for any assay parameter, but the curve for the viability index (Figure 1) indicated that an EC50 would occur near 35 µl/ml. In terms of the volume of exhaust gas represented by the DMSO test solution (4346.5 L gas/ml), this EC50 corresponds to 152.1 L gas/ml. Therefore, on the basis of the viability index and expectations for the ATP and protein parameters, the test material appears to yield EC50 values in the low toxicity region (100 L/ml to 1000 L/ml).

IX. CONCLUSIONS:

The test material, SASS train XAD-2 Extract, Oil Fired Gas Turbine No. 1, is evaluated as having low toxicity to WI-38 human cells. The viability index indicated an EC50 value would be obtained near 152 L gas/ml, and the ATP and protein contents were decreasing in the same toxicity range.

Submitted by:

Study Director

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TABLE I

WI-38 HUMAN CELL CYTOTOXICITY ASSAY

Test Date: MAY 29, 1979	Initial Cell Viability: 97.2%
LBI Assay No.: 3986	Viable WI-38 Cells Seeded/Flask: 2.0×10^5
Test Material Identity: Oil Fired Gas Turbine No. 1, SASS Train XAD-2 Extract	Passage number: 28

Vehicle: DMSO/growth medium

TEST RESULTS

		Average Values per Culture Flask				ATP Per		Expressed as Percent of Negative Control (NC)***				
Sample	Concentration†† µl/ml	Viable Cells 10^6 Units	Total Cells 10^6 Units	Cellular Protein µg	ATP 10^8 fg	10^6 Cells 10^8 fg	Viability %	Viability	Viability Index	Protein	ATP	ATP Per 10^6 Cells
NEGATIVE CONTROL	---	.602	.610	145	50.4	82.6	98.7%	100.0	100.0	100.0	100.0	100.0
1% DMSO BLANK S.E.**		.448	.449	101	43.3	96.4	99.8	101.1	74.4	69.7	85.9	116.7
1% DMSO†		.446	.446	98	38.9	87.2	100.0	101.3	74.1	67.6	77.2	105.6
2% DMSO BLANK S.E.**		.463	.481	80	33.1	68.8	96.3	97.6	76.9	55.2	65.7	83.3
2% DMSO		.397	.406	55	27.3	67.2	97.8	99.1	65.9	37.9	54.2	81.4
TEST	0.5	.467	.473	100	43.3	91.5	98.7	98.9	104.2	99.0	100.0	94.9
TEST	2.0	.453	.454	102	39.0	85.9	99.8	100.0	101.1	101.0	90.1	89.1
TEST	5.0	.420	.425	91	39.4	92.7	98.8	99.0	93.8	90.1	91.0	96.2
TEST	10.0	.411	.420	79	38.9	92.6	97.9	98.1	91.7	78.2	89.8	96.1
TEST	20.0	.325	.333	61	27.5	82.6	97.6	101.3	70.2	76.3	83.1	120.1
							*EC50 VALUES: µl/ml	>20.0	(35)	>20.0	>20.0	>20.0

††pH change in culture medium: None observed

** 1.2 ml methylene chloride solvent exchanged to 2.0 ml DMSO

*** or appropriate DMSO blank

*Determined from data plots in Figures 1 and 2

†Average of 2 flasks

Toxicity
Classification: Low toxicity

FIGURE 1

EC50 DETERMINATION FOR

PERCENT VIABILITY (O) AND VIABILITY INDEX (●)

OIL FIRED GAS TURBINE NO. 1

SASS TRAIN XAD-2 EXTRACT

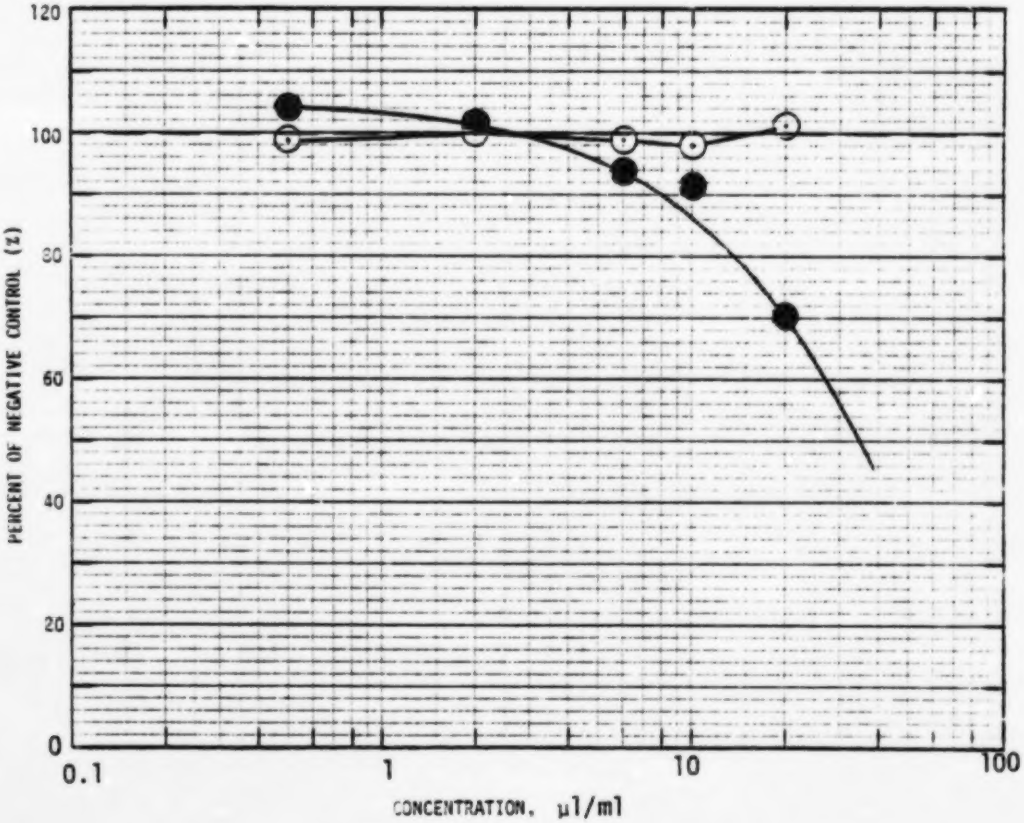


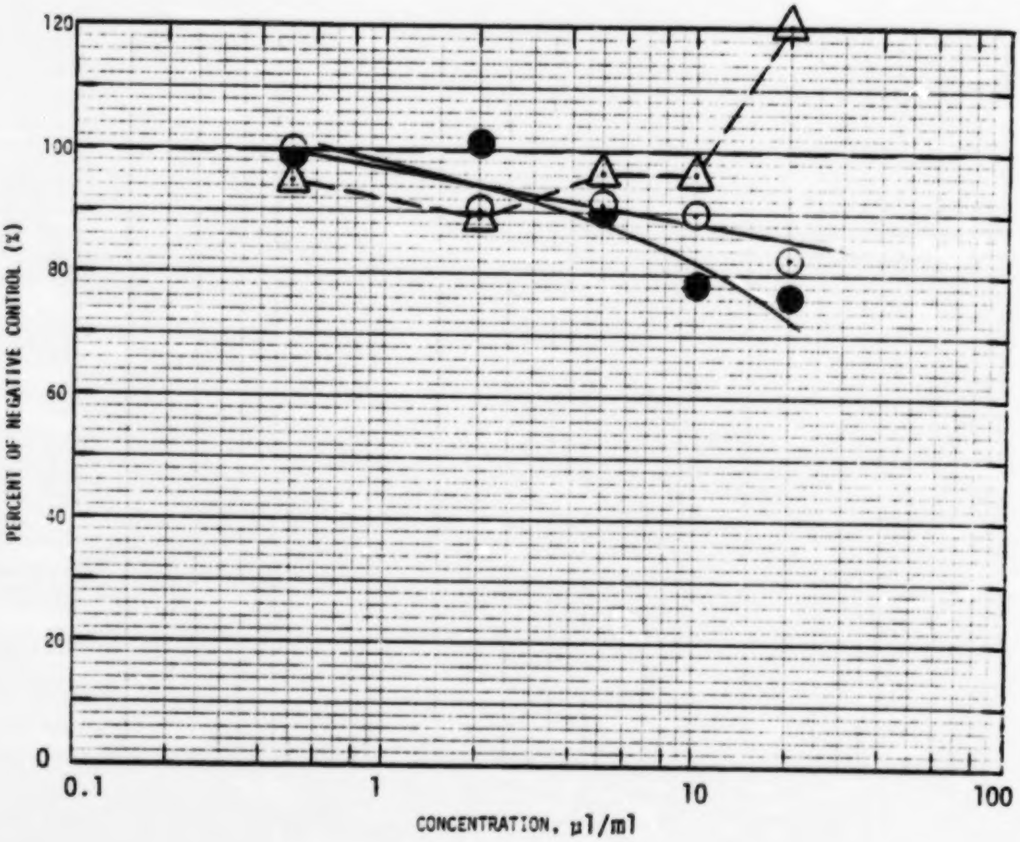
FIGURE 2

EC50 DETERMINATION FOR

PROTEIN (●), ATP (O), and ATP/10^6 CELLS (Δ)

OIL FIRED GAS TURBINE NO. 1

SASS TRAIN XAD-2 EXTRACT



ASSAY PROTOCOL

1. OBJECTIVE

The objective of this assay is to determine the concentrations of test material that reduces by 50% the number of viable cells, the cellular protein, and the ATP content after a 20 hour exposure. These concentrations are referred to as the EC50 values for each measured parameter.

2. MATERIALS

A. Indicator Cells

The indicator cells used for this study were WI-38 human embryonic lung fibroblasts obtained from Flow Laboratories, Inc., Rockville, Maryland. The cells were supplied as confluent monolayers at passage numbers 23 or 24 in Eagle's Minimum Essential Medium. This test system is specified by the Environmental Protection Agency's Level 1 Environmental Assessment Program.[1]

B. Medium and Cell Maintenance

The cells were maintained and treated in Basal Medium Eagle (BME) supplemented with 10% fetal bovine serum, 2mM L-glutamine, 100 units/ml penicillin, 100 μg/ml streptomycin, and 1.0 μg/ml amphotericin B (Fungizone). Subcultures were prepared twice weekly at a 1:2 split ratio using 0.25% trypsin. Cultures were discarded after the 35th subculture (passage).

C. Negative Controls

Five sets of negative control cultures, each in triplicate, were carried through the same experimental time period as the treated cells. One set was an untreated negative control consisting of cultures exposed only to BME culture medium. Two sets were solvent controls containing 1% and 2% of the solvent-exchanged DMSO blank, prepared as described below. In addition, two solvent control sets containing 1% and 2% pure DMSO were assayed in order to determine whether residual methylene chloride in the solvent-exchanged blank was contributing to solvent toxicity. The average viability, ATP content, and protein content of the solvent-exchanged negative controls provided the reference points for determining the effects of different concentrations of the test material on the assay parameters. The 2% solvent-exchanged control was the reference for the highest assayed concentration (20 μl/ml) and the 1% solvent-exchanged control was the reference for the remaining test concentrations.

2. MATERIALS (Continued)

D. Sample Preparation and Handling

The test material was received as a solution in 1.2 ml of methylene chloride and was stored at 4°C until solvent exchanged. The entire sample was exchanged into DMSO by first adding 2 ml DMSO and reducing the volume to 2 ml under a stream of nitrogen in a warm water bath (33°C). Then 0.5 ml DMSO was added and the solution evaporated again to 2 ml. This last process was repeated once more, leaving the sample in a final volume of 2.0 ml. This sample was stored at 4°C until use in the cytotoxicity assay. Since the original test sample represented 307 ft^3 of exhaust gas, the solvent exchanged sample corresponded to 153.5 ft^3 gas/ml or 4346.5 L gas/ml.

A solvent exchanged DMSO blank was also prepared by the above procedure, starting with 1.2 ml methylene chloride (same volume as the original test material).

3. EXPERIMENTAL DESIGN

A. Dose Selection

The solvent exchanged sample was tested from 20 µl/ml to 0.5 µl/ml in five dose steps. The 20 µl/ml treatment was the maximum dose because of the introduction of 2% DMSO in the growth medium. All other concentrations were obtained by 1:100 dilutions of the test sample and dilutions thereof (using DMSO) into the growth medium to give a 1% final concentration of solvent.

B. Culture Preparation

Stock cultures were subcultured into 100-mm plastic culture dishes 24 to 72 hours prior to use. This procedure provides a population of actively growing, sub-confluent cells to initiate the assay.

The cells were then suspended in BME culture medium by treatment with 0.25% trypsin for 3-5 minutes and the cell number determined by hemocytometer. A series of 25-cm^2 culture flasks were seeded with 20 x 10^4 cells and 4 ml culture medium per flask. The cultures were incubated overnight at 37°C in a humidified atmosphere containing 5% CO_2 to allow attachment of the cells and resumption of growth.

3. EXPERIMENTAL DESIGN (Continued)

C. Treatment

The medium was aspirated from the cultures and 4 ml of BME culture medium containing the test sample was applied. Three cultures were exposed to each test concentration and solvent exchanged DMSO blank. The flasks were then placed on a rocker platform in a 37°C incubator with a humidified atmosphere containing 5% CO_2. The flasks were slowly rocked for a 20 hour exposure period. Any color changes in the culture medium caused by the test material were noted and the pH determined in additional treated flasks.

D. Cell Viability Assay

At the end of the treatment period, the medium containing unattached cells was decanted into a centrifuge tube on ice. The cell monolayer was washed with 1 ml 0.05% trypsin/versene and this wash combined with the decanted media. The attached cells were then removed with 2 ml of 0.25% trypsin at 37°C and the suspended cells combined with the decantate. The cells from each flask were thereby resuspended in 7 ml volumes for subsequent analysis.

A 1.0 ml aliquot was removed for cell count and viability determination. The aliquot was combined with 0.2 ml or 0.5 ml of 0.4% trypan blue and counted by hemocytometer about 5 to 15 minutes later. Between 60 and 154 cells were counted per flask and the number of live (colorless) and dead (blue) cells were recorded.

E. ATP Assay

ATP was immediately analyzed by extraction of a 0.1 ml cell suspension sample with 0.9 ml of 90% DMSO. After 2 minutes at room temperature, 5.0 ml cold MOPS buffer (0.01 M morpholinopropane sulfonic acid) at pH 7.4 was added and the extract was vortexed and placed on ice. Aliquots of 10 μl were injected into a cuvette containing a luciferin-luciferase reaction mixture in a DuPont Model 760 Luminescence Biometer. The Biometer was calibrated with standard ATP solutions to provide a direct read-out of the ATP content. Each test sample was assayed three times to demonstrate consistent readings.

F. Lowry Protein Assay[2]

A 3.0 ml aliquot of the cell suspension was taken for protein analysis by the Lowry method. The aliquot was centrifuged at 365 x g for 10 minutes, the medium decanted, and the cell pellet resuspended in 3 ml PBS. After two additional centrifugation washes with PBS, the pellet was resuspended in 1.5 ml of PBS and frozen at -20°C or analyzed immediately. A 1.0 ml aliquot was used for the Lowry assay.

3. EXPERIMENTAL DESIGN (Continued)

At the end of the color development period, the tubes were centrifuged to remove any particulate test material prior to making absorbance readings at 750 nm. Lowry protein standard curves were constructed with bovine serum albumin for each assay.

4. REFERENCES

[1] IERL-RTP Procedures Manual: Level I. EPA-600/7-77-043, April 1977.

[2] Lowry, O.H., Rosebrough, N.J., Farr, A.L., and Randall, R.J.: Protein Measurement with Folin Phenol Reagent. J.Bio.Chem., 193:265-275, 1951.

ASSAY ACCEPTANCE CRITERIA

The assay will be considered acceptable for evaluation of the test results if the following criteria are met:

1. The passage level of the cells (number of subcultures) prior to use in the assay does not exceed 35.
2. The percent viability of the WI-38 cells used to initiate the assay is 95% or greater.
3. At least 1.5×10^5 cells are seeded per flask. The untreated negative control cultures must increase in cell number by at least 2-fold over the 20 hour treatment period.
4. A sufficient number of data points (for five test concentrations or less) are available to clearly locate the EC50 of the most sensitive test parameter within a toxicity region as defined under Evaluation Criteria.
5. The data points critical to the location of the EC50 for the most sensitive parameter are the averages of at least two treated cultures.
6. If all the test parameters yield EC50 values greater than 1000 µg/ml or 600 µl/ml, the plotted curves for any parameter will not exceed 120% of the negative control.

ASSAY EVALUATION CRITERIA

The EC50 value represents the concentration of test material that reduces an assay parameter to 50% of the negative control value. EC50 values are determined graphically by fitting a curve by eye through the data points associated with each test parameter plotted as a function of the logarithm of the applied concentration. Each point normally represents the average of three culture flasks for each treatment. Statistical analysis is unnecessary in most cases for evaluation.

The evaluation of the test material is based upon determinations of the EC50 values for five parameters: percent viability (ratio of viable cells to total cells x 100% for each treatment), viability index (ratio of viable cells for each treatment to viable cells in the negative control x 100%), cellular protein, total ATP content, and ATP per 10^6 cells. Except for the ATP content, these parameters are specified in the EPA Procedures Manual.[1] The ATP content will generally be a more sensitive parameter than ATP per 10^6 cells because any cell loss due to treatment will increase the latter parameter. ATP released into the growth medium by disrupted cells contributes to the ATP measurement.

The toxicity of the test material is evaluated as high, moderate, low or nondetectable according to the ranges of EC50 values defined in the following table. The actual concentration of extract at the EC50 is converted to the equivalent volume of exhaust gas per milliliter of culture medium prior to the evaluation. The assay parameter yielding the lowest EC50 will classify the test material.

Toxicity*	EC50 Values
High	EC50 < 10 L gas/ml
Moderate	EC50 range of 10-100 L gas/ml
Low	EC50 range of 100-1000 L gas/ml
Nondetectable	EC50 > 1000 L gas/ml

*Formulated by Litton Bionetics, Inc., under contract to the Environmental Protection Agency, Contract No. 68-02-2681.